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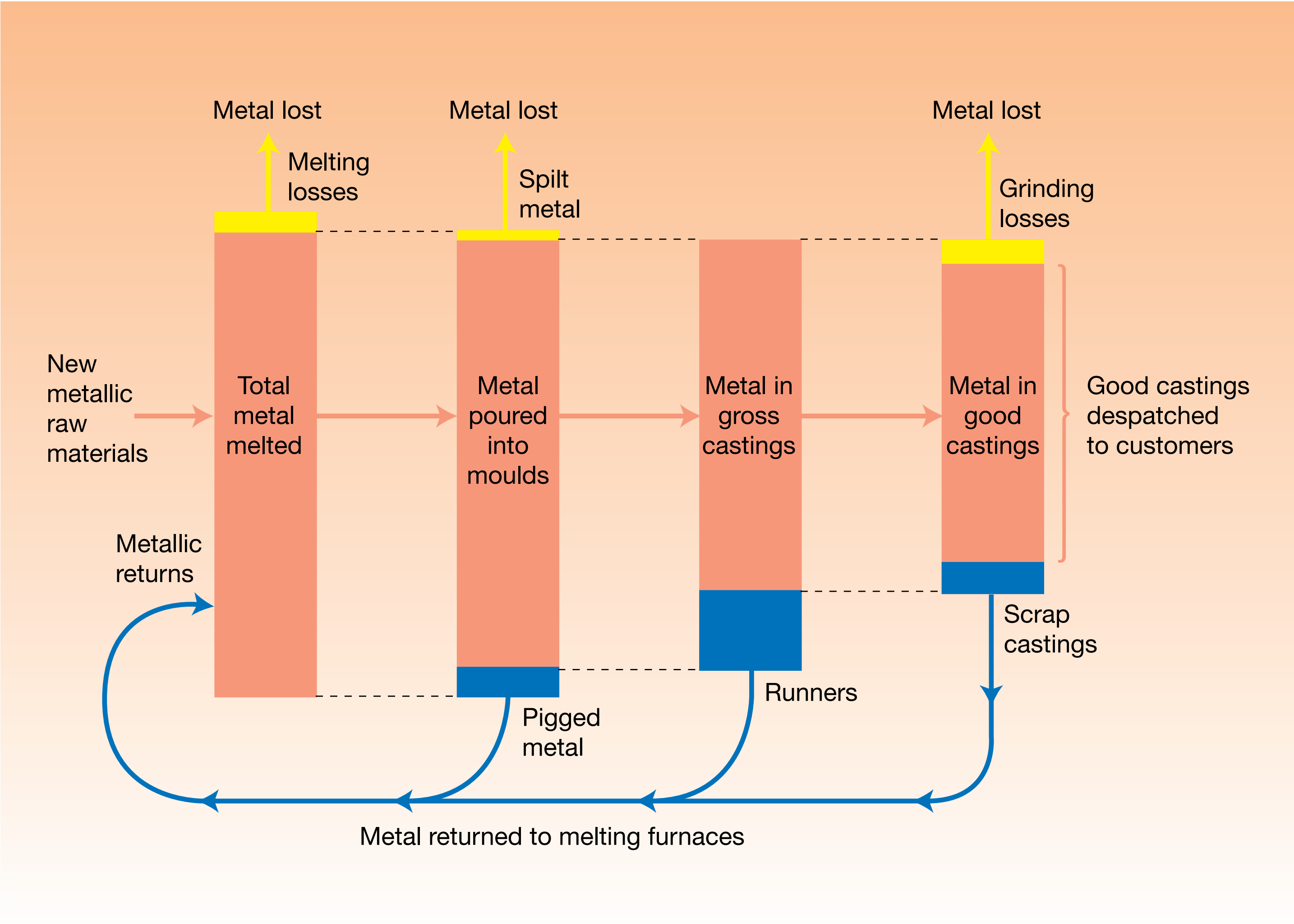
GOOD PRACTICE GUIDE 17

Achieving high yields in iron foundries



ENERGY EFFICIENCY
BEST PRACTICE PROGRAMME

ACHIEVING HIGH YIELDS IN IRON FOUNDRIES

This Guide is No 17 in the Good Practice Guide series. It considers the various processes within a foundry and examines particular actions that can be taken to improve yields. Checklists are provided to give the reader a quick reference to the main areas where yield can be improved.

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FOREWORD

This Guide is part of a series produced by the Department of the Environment, Transport and the Regions under the Energy Efficiency Best Practice Programme. The aim of the programme is to advance and spread good practice in energy efficiency by providing independent, authoritative advice and information on good energy efficiency practices. Best Practice is a collaborative programme targeted towards energy users and decision makers in industry, the commercial and public sectors, and building sectors including housing. It comprises four inter-related elements identified by colour-coded strips for easy reference:

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SUMMARY

This Guide is a revision of an earlier version first published in 1990. It reflects the changing emphasis in yield and the tools available to the foundry operator for improving it.

Yield is a measure of a foundry's ability to manufacture saleable castings in an effective manner. While yield is dependant on product mix and types and grades of iron produced, it is found to vary considerably between individual foundries serving similar markets and employing identical methods of production.

Improving yield offers many commercial and environmental benefits to a foundry. Along with the direct energy savings it offers, high yield is also associated with better process control, and therefore improved cost control. The knock-on benefits of improved productivity, better quality castings and better customer relations, particularly on scrap related issues, cannot be overstated.

It is estimated that between 1981 and 1994, the overall yield in foundries improved by 3.3% (after taking into account changes in the nature and metallurgy of castings produced). Based on 1997 costs, this represents annual savings of £5 million in energy for the UK iron foundry sector. In addition, direct savings to sand, non-recoverable metal, consumable items and effort are probably of equivalent or greater value. This is reflected in reduced operating costs for enlightened foundries together with a significant reduction in greenhouse gas emissions.

Although yield has improved over recent years, there are still plenty of opportunities for it to improve yet further. This Guide outlines the various approaches which the individual foundry should follow to improve casting yield and hence its 'bottom line' performance. Emphasis is placed on the need for honesty, both at the commencement of any exercise and throughout its duration.

Advice is provided on improved methoding to enhance box yield, design optimisation, simulation packages, lightweighting and defect reduction. The importance of controlling melting, metal distribution and pouring is highlighted. In addition, the various process parameters are reviewed, and the need to control them in the context of reducing scrap is indicated. Emphasis is placed on establishing a strategy through which effective scrap reductions can be achieved.

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Figures

1. INTRODUCTION

1.1 The Importance of Yield

Yield is usually defined as the total weight of good, saleable castings expressed as a percentage of the total weight of metallic materials melted to produce them. This can be represented by:

$$\text{yield (\%)} = \frac{\text{total weight of good castings}}{\text{total weight of metal melted}} \times 100$$

Iron foundries melt approximately 2.3 million tonnes of metal annually in producing 1.4 million tonnes of castings at an energy cost of £104 million. Energy represents one of the largest 'controllable' costs in melting, and improved yield is one of the best ways of reducing this cost.

1.2 Metal Balance

Actual yield is less than 100% because the weight of metal melted always exceeds that of good castings dispatched. The progress of metal from melting to castings dispatch is shown in the metal balance diagram (Fig 1). This illustrates the various stages during which metal is either irredeemably lost or re-routed through the foundry, both of which influence the final yield obtained. Non-recoverable losses occur during:

- the melting operation (through oxidation, slagging operations, test pieces, etc.);
- distribution and pouring (as spillage);
- fettling (as metal chippings or material ground-off castings).

The above material losses generally represent between 5% and 10% of the total metal melted, a costly exercise when the value of metal and energy input is considered. The balance of the excess melted metal, i.e. pigged metal, running systems and scrap castings, is generally returned for remelting.

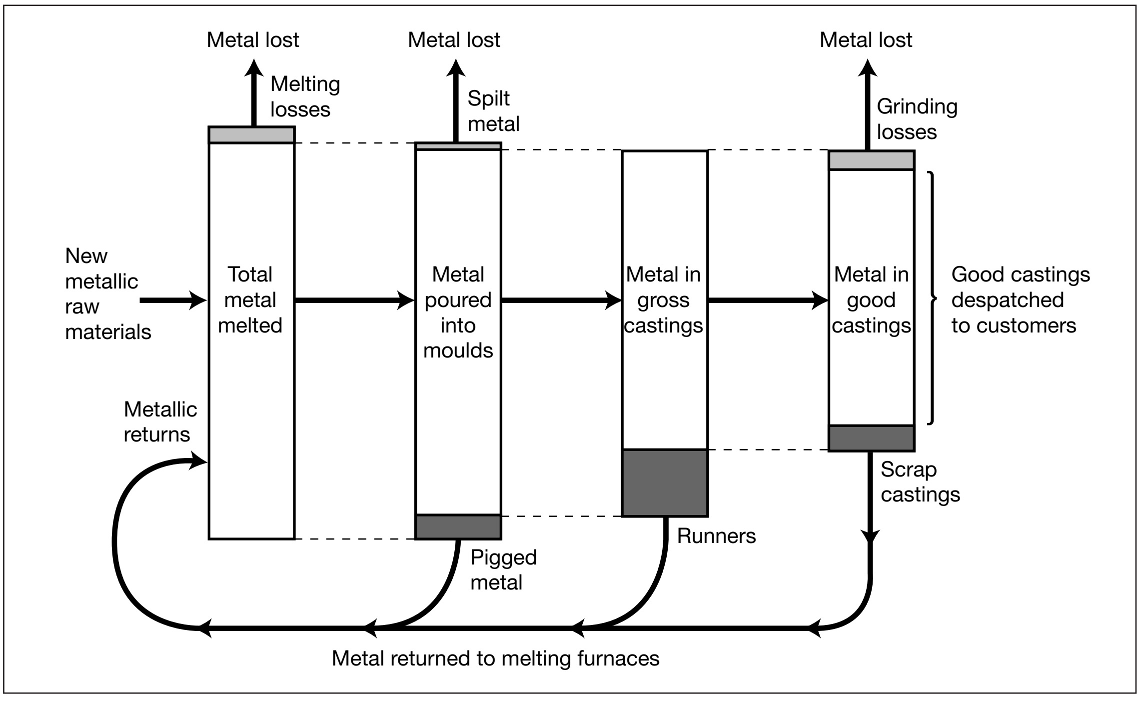


Fig 1 Routes taken by metal from melting to castings dispatch

Yield varies considerably from one foundry to another, depending mainly upon the type of casting produced and grade of metal concerned. For example, a typical grey iron foundry will operate at an overall yield of approximately 65%. Thus, for every 100 tonnes of metal charged, the foundry produces 65 tonnes of saleable castings. Malleable iron castings may achieve only a 35 to 45% yield and ductile iron a 45 to 80% yield, while specialized grey iron castings may provide a yield as high as 90%.

1.3 Energy Consumption

The most recent survey of energy consumption in UK iron foundries was carried out in 1995 under the Energy Efficiency Best Practice Programme (EEBPP). The results are reported in Energy Consumption Guide 48, *UK iron foundry industry*, and include a breakdown of overall energy usage in castings manufacture (Table 1, Figs 2 and 3).

Table 1 Breakdown of overall energy usage

Energy usage	**Proportion of the total processing energy (%)**	
	Supplied	**Primary**
Melting and holding of molten metal	62.56	57.51
Ladle heating	5.27	2.80
Moulding	6.39	10.70
Coremaking	2.40	4.00
Heat treatment	1.34	1.46
Foundry lighting	1.44	2.42
Foundry space heating	5.60	2.98
Office lighting	0.80	1.34
Office heating	1.92	1.02
Compressed air	3.83	6.43
Remainder - internal layout fume and dust extraction, finishing operations, sand reclamation	8.45	9.34
Total	**100.00**	**100.00**

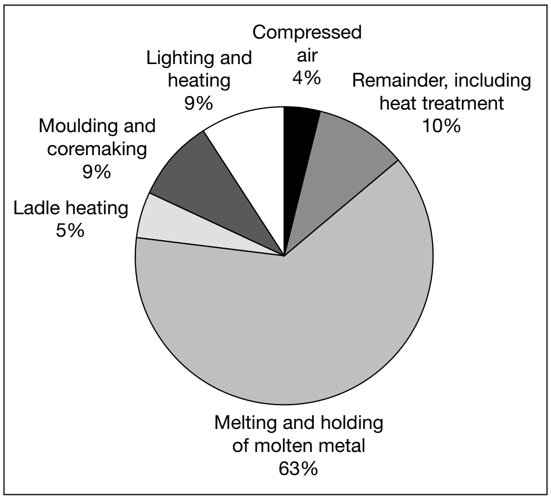


Fig 2 Supplied energy

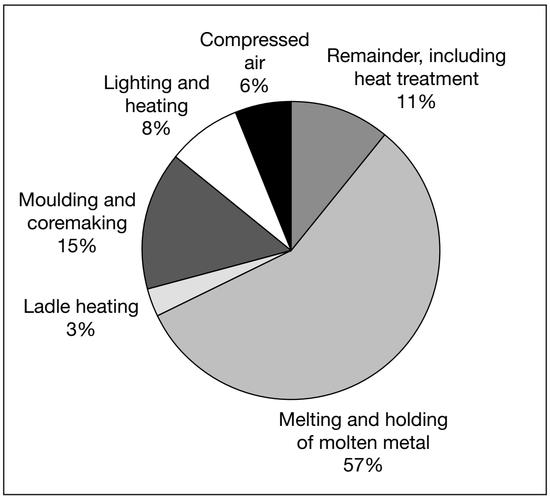


Fig 3 Primary energy

The quantity of energy consumed by the melting process is approximately proportional to the amount of metal melted. As melting operations consume more than half of the total energy requirement of many iron foundries, improving yield performance makes a worthwhile reduction to a foundry's overall operating costs.

Achieving high yield depends largely on the application of good foundry practice, the key areas of which are: melting, pouring, moulding and coremaking.

The melting and pouring areas must be both equipped and organised to deliver metal into the moulds at the appropriate temperature and required composition. While it is important that unsatisfactory metal is pigged rather than poured into moulds, the amount of pigged metal should be monitored and action taken if it becomes excessive.

The production of defective castings is another important issue that has to be addressed. Reducing scrap has a two-fold effect:

- less energy is required for metal melting;
- materials, consumable items and labour (particularly in moulding, coremaking and the post-casting processes) are also reduced, thus increasing the foundry's potential capacity.

The savings that can be achieved by improving foundry yield are not always appreciated by companies. For example, if a foundry that normally produces 50 tonnes of good castings from every 100 tonnes of metal melted (i.e. a yield of 50%) increased this to 60%, only 83.3 tonnes of molten metal would be required, thereby reducing the melt by 16.7 tonnes.

Extending this argument further, if the foundry in question used a cupola furnace with a 14% coke charge, there would be a saving of approximately 2.4 tonnes of coke for every 50 tonnes of good castings produced, thus saving £8 of coke per tonne of castings. In the case of electric melting, and based upon an energy consumption of 680 kWh/tonne of metal melted, the foundry in this example would achieve an equivalent saving of about 11,000 kWh. Assuming an electricity cost of 5 p/kWh, a 10% increase in yield would provide energy savings of £11/tonne on saleable castings.

Taking this analysis further, if the entire UK iron foundry sector were to improve its yield by 2%, energy savings in excess of £3 million per annum would be achieved, and the UK's generation of carbon dioxide (CO_2) would be reduced by 70,000 tonnes.

1.4 Assessment of Yield

Before foundry yield can be improved, the existing yield must be measured accurately; in this context, honesty is a vital prerequisite. The following must be verified: that the weight of metal actually melted is consistent with what is claimed; that the weight of castings dispatched is known. The true quantities of customer and foundry scrap are also important. A metal balance of the form shown earlier (see Fig 1), indicating where molten iron is being consumed, can help highlight the priorities for action.

It is important to break down foundry yields in accordance with the type of metal melted and the different moulding techniques used. Targets for yield performance should be established for each foundry.

The main processes within a foundry are examined in this Guide and practical advice is offered on ways in which yield can be improved.

2. THE KEY ROLE OF EFFICIENT METHODING

2.1 Improving Box Yield

Good methoding is vital when trying to achieve a high foundry yield. There are two main ways in which the skills of the methods engineer can improve yield:

- Careful planning in the layout of patterns and the provision of optimum running and feeding systems should enhance the box yield by increasing the ratio of the weight of castings produced to that of the running system, a vital factor with multi-pattern layouts.
- The incidence of scrap arising at the foundry and in the customer's machine shops will be reduced if running systems are properly designed.

Box yield can be defined as the weight of metal contained in the castings produced in the mould (i.e. with running and feeding systems discounted) expressed as a percentage of the weight of molten metal poured into the mould.

$$\text{box yield (\%)} \quad = \quad \frac{\text{weight of castings in mould}}{\text{weight of metal poured into mould}} \times 100$$

In most circumstances, if an extra casting(s) can be incorporated into a mould, this will considerably improve the box yield. Ingenuity is frequently required to achieve this, and extra castings must not be secured at the expense of raising the scrap rate. Figs 4 and 5 show examples where the number of castings per mould has been increased from two to three and three to four respectively. In the first example, a change in box yield from 39 to 65% has been achieved; in the second, an improvement from 32 to 48%.

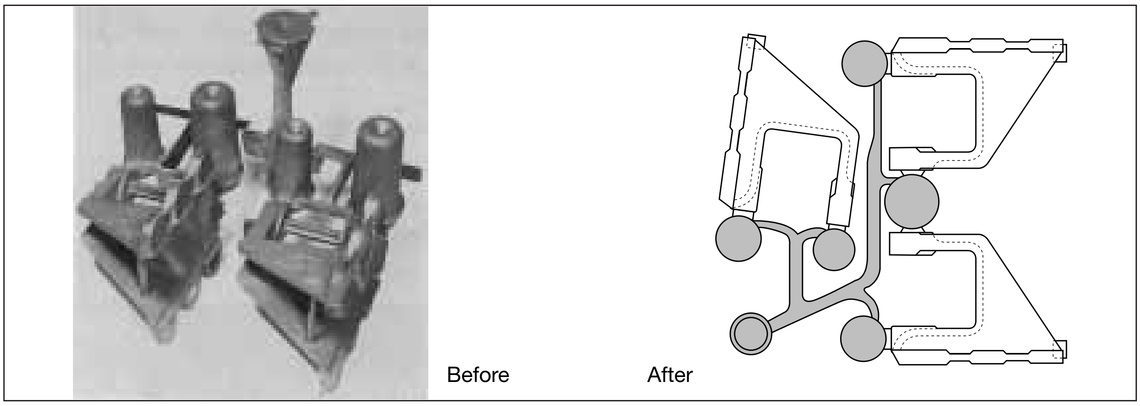


Fig 4 Increase in castings from two to three

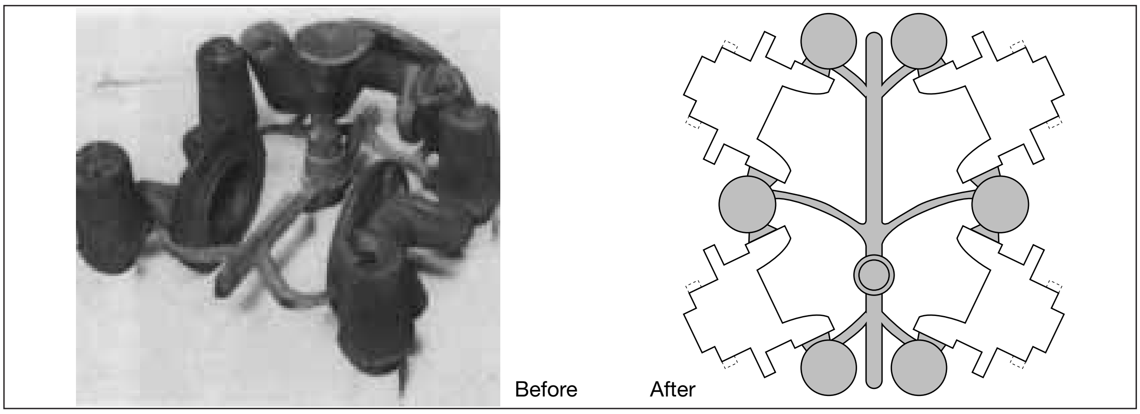


Fig 5 Increase in castings from three to four

The following well-established techniques should always be examined when considering the possibility of increasing box yield:

- **Riders.** The practice of adding 'fill-in' or 'ride-on' castings into vacant spaces in a mould can improve box yield.
- **Redesign.** Occasionally, a casting may be redesigned so that a core(s) can be eliminated. This means that space previously used for coreprints is no longer needed, possibly providing an opportunity to fit more castings into the mould.
- **Stack moulding.** Certain castings can be produced by stack moulding techniques, resulting in very high box yields.
- **Ceramic shell moulding.** Many castings can now be produced by this technology, e.g. the Replicast process, which effectively uses the principles of investment casting but employs expanded polystyrene instead of wax. There are now many examples of both significant cost savings and improved yield achieved through this process.

2.2 Components of the Gating System

Running is the practice of providing a series of channels, called a gating system, through which metal can flow into the mould. The basic principles in designing good running and feeding systems are well-established to maximise both casting yield and box yield, while at the same time guaranteeing casting integrity and the prevention of defective castings. In this context, the emphasis is on:

- reducing metal turbulence during pouring;
- achieving directional solidification;
- preventing mould/core erosion;
- avoiding the ingress of slag;
- providing a uniform temperature distribution.

The basic components of a running and feeding system are shown in Fig 6.

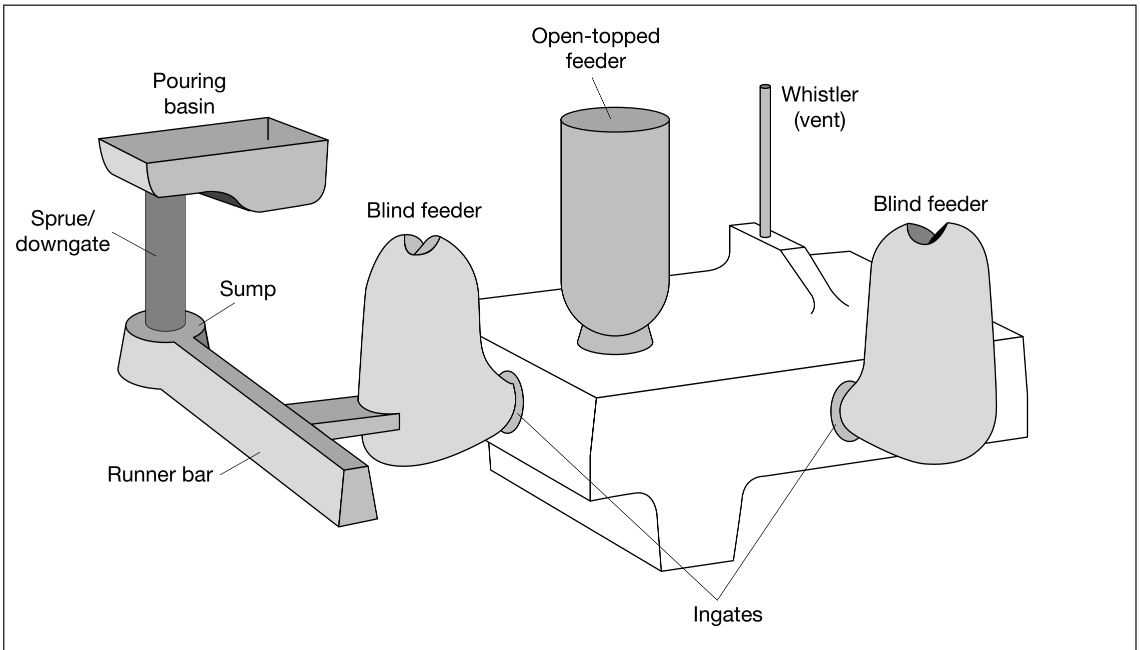


Fig 6 Components of a running and feeding system

It is not the intention of this Guide to outline in detail the function of all the components of the running and feeding systems commonly used, or the parameters that control their performance. However, the dimensioning, choice, and placement of the various components will directly

influence casting integrity and yield. Decisions on the optimum pouring rate, metal distribution, and the need for filters/slag traps and feeding requirements, to ensure casting soundness, is that of the methods engineer. The ability to make these decisions is a skill that is still paramount, even when sophisticated software support is used (see Section 2.4).

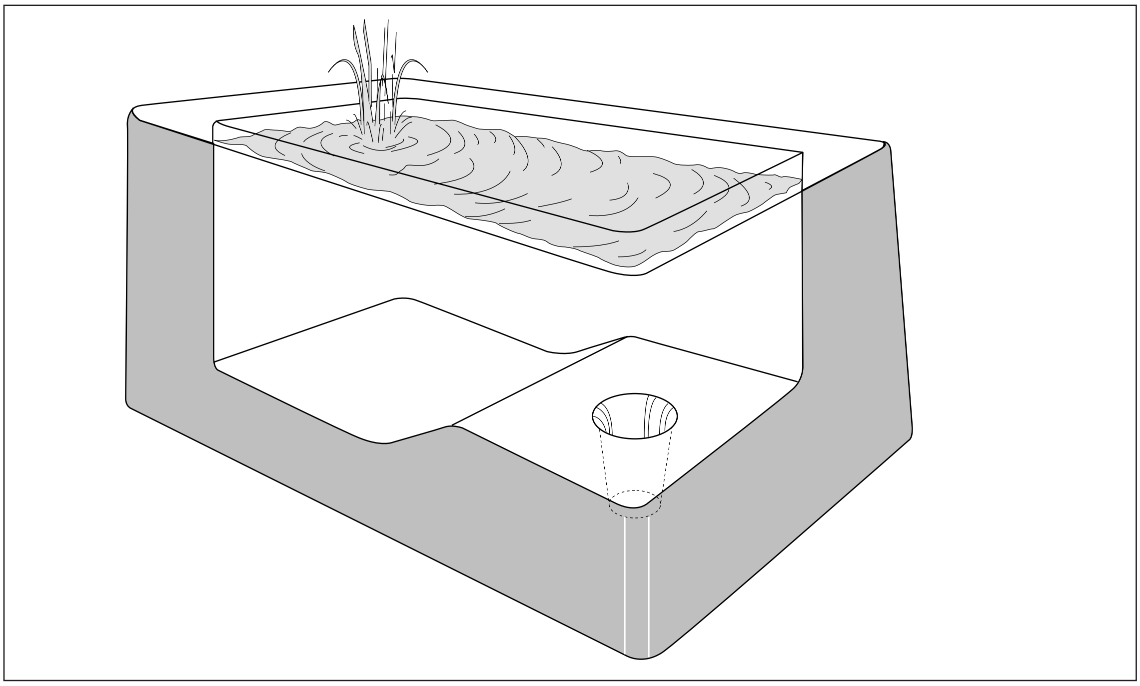
Unfortunately, often through ignorance or by the application of excessive safety factors, running and feeding systems are frequently overspecified or incorrectly designed, leading to either reduced yield or the production of defective castings. The following are simple guidelines that should be considered when designing a running and feeding system[1] for iron castings.

2.2.1 *Pouring Basin*

The main purpose of the pouring basin is to:

- prevent the first metal poured from passing immediately down the sprue;
- provide a sufficient head of metal to stop the creation of a vortex above the sprue, thereby reducing turbulence;
- offer an ample target for rapid filling, and prevention of air aspiration.

Precautions must be taken to ensure that the design of the basin does not adversely affect casting yield. To meet all the criteria, a basin of the type shown in Fig 7 is recommended, where applicable, although yield can be improved by making it pear-shaped (Fig 8) rather than rectangular. The incorporation of a slag dam (Fig 9) helps promote the production of cleaner castings.



Source: International Mechanite Metal Company Ltd

Fig 7 Pouring basin

The ideal is not always achievable with high-volume greensand moulding lines because the production of the pouring basin is encompassed in the sprue-cutting operation.

In certain instances, ceramic strainer cores, fusible metal stoppers, skimmer cores, etc. can be used to improve performance, albeit at additional cost.

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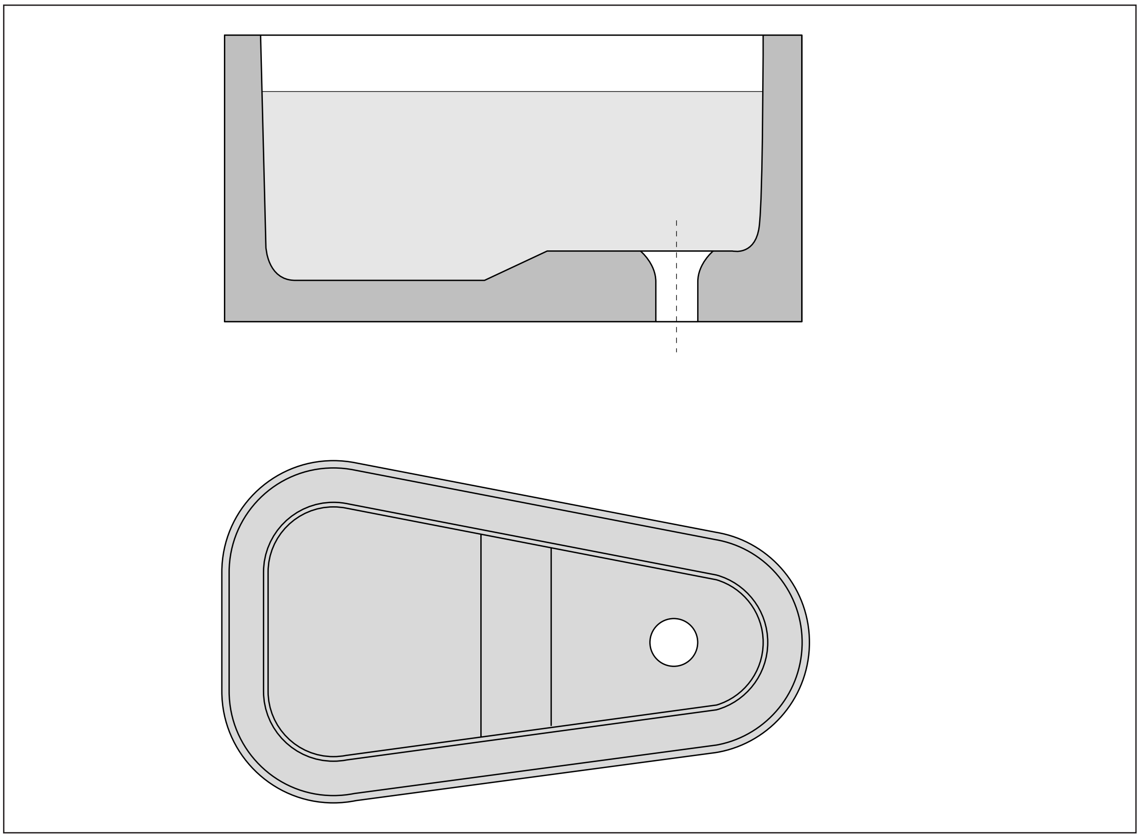
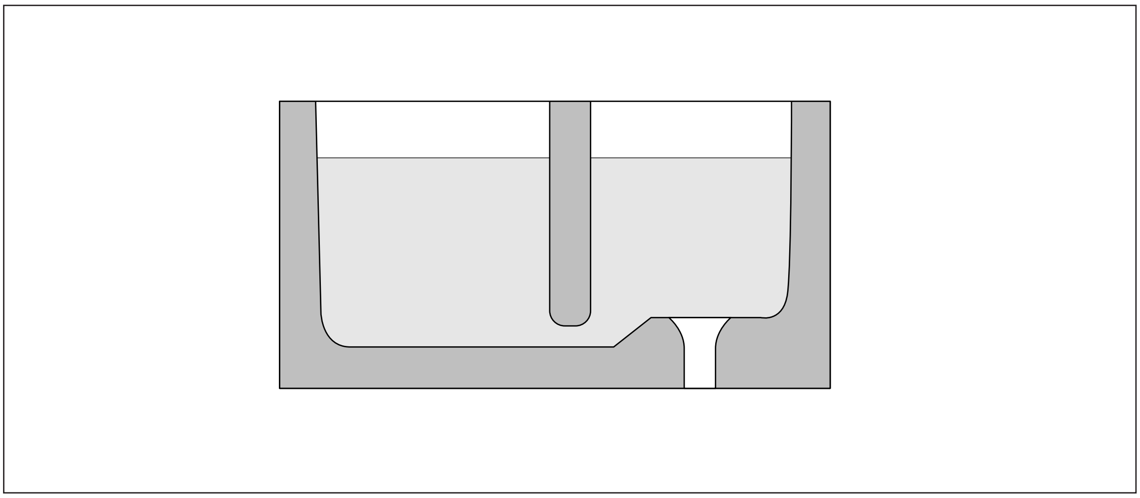
[1] Feeding practice is covered in greater detail in Section 2.3.



Source: International Mechanite Metal Company Ltd

Fig 8 Improved pouring basin design



Source: International Mechanite Metal Company Ltd

Fig 9 Pouring basin incorporating a slag dam

2.2.2 *Sprue or Downgate*

When molten metal falls through an orifice, it accelerates under the influence of gravity and hence the cross-sectional area of the metal stream is reduced. It is therefore desirable to taper the sprue downwards so that turbulence, gas entrapment and erosion are minimised.

However, for practical reasons the parallel sprue is the shape most commonly adopted. A sprue with a rectangular cross-section is less prone to inducing a vortex than one that has a circular cross-section, and is often used for larger castings. However, it is preferable to radius the corners of all sprues with a rectangular cross section.

2.2.3 *Sump/Runner Bar*

Located at the base of the sprue, the sump provides a chamber which will receive the rush of molten metal entering the runner bar. To reduce turbulence and air entrapment, it is important to minimise the number of abrupt directional and sectional changes.

2.2.4 *Runner Extension*

In order to prevent the first metal entering the gating system and passing directly into the mould cavity, it is beneficial to provide a runner extension. This collects what is generally the coldest metal carrying the greatest amount of inclusions (Fig 10).

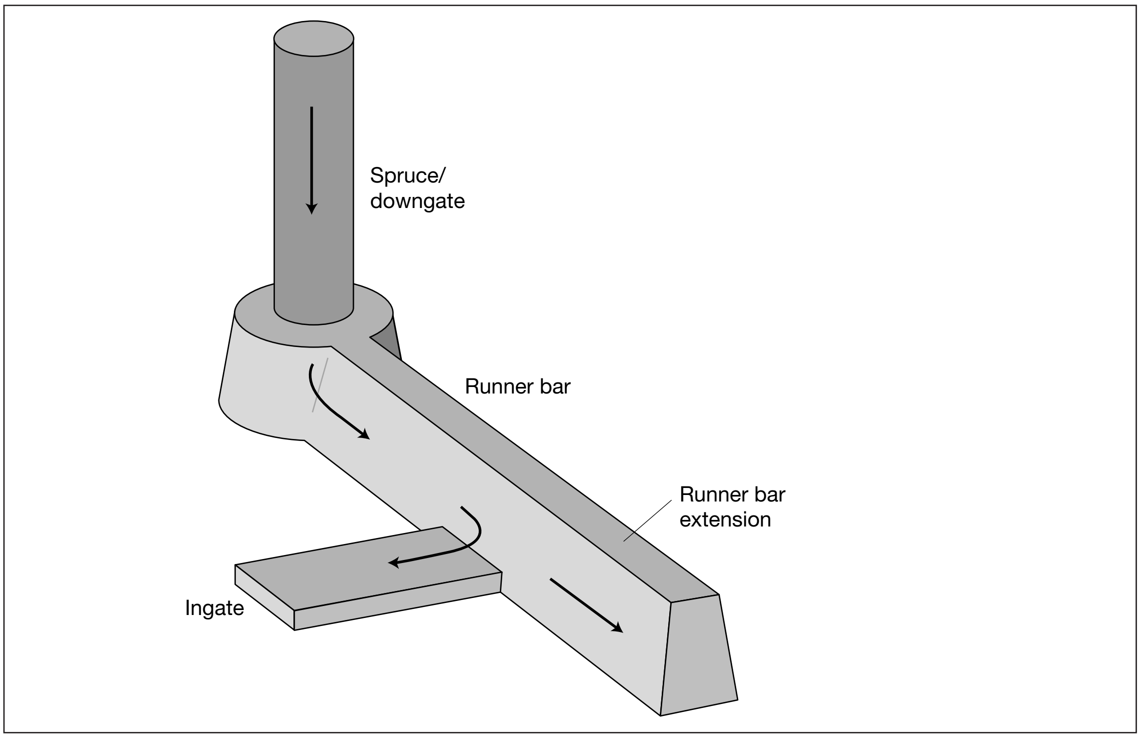


Fig 10 Runner bar extension

2.2.5 *Ingates*

Ingates direct metal from the runners into the mould cavities. In practice, it is desirable to connect them to the runner bar so that the cleanest metal is taken from the base (without turbulence or erosion). A ‘rule of thumb’ for the minimum ratio of runner bar to total ingate cross-sectional area is 4:1.

Ingates should be positioned to avoid direct impingement of molten metal onto any cores, or the mould cavity itself, and to ensure that it is distributed in such a way as to ensure maximum casting soundness and freedom from residual stresses.

2.2.6 *Slag Traps*

A slag trap, e.g. a runner bar extension, or the careful design of runners in relation to ingates, are common methods used to keep unwanted inclusions out of the casting. However, specific traps can be incorporated in the gating system. Typical examples are the centripetal trap or ‘spinner’, which relies on the separation of slag and metal by spinning and flotation, and the saw tooth trap on the runner bar, which creates a choking action (Fig 11). The spinner trap is the least desirable because it reduces box yield.

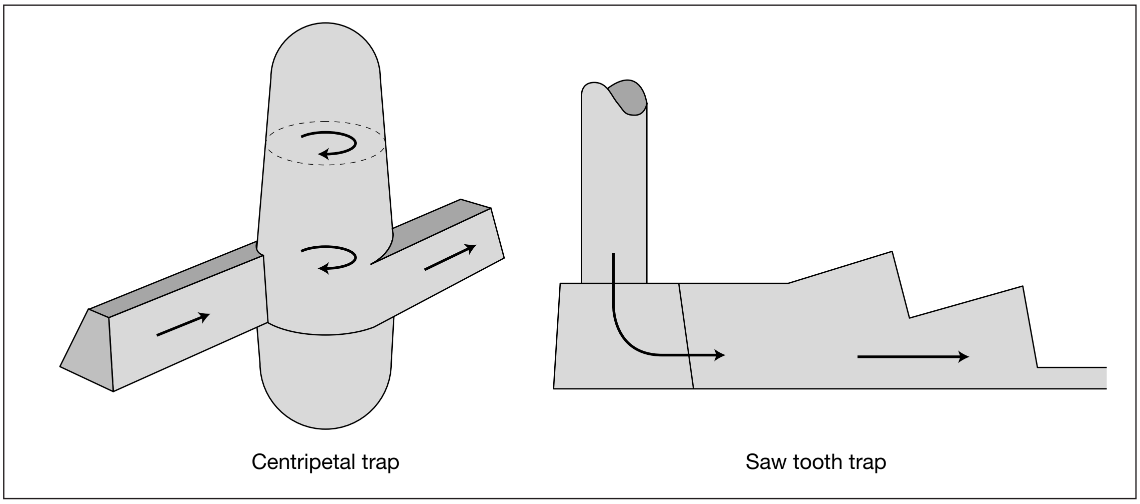


Fig 11 Designs for runner bar slag traps

2.2.7 *Filters*

The occurrence of non-metallic inclusions in castings is one of the most widespread causes of casting defects encountered. Inclusions not only raise the incidence of scrap (which has an adverse effect on yield) but also have a deleterious effect on casting surface finish, mechanical properties, machining characteristics, and pressure tightness. Ultimately, they can lead to the rejection of castings.

Traditionally, the incidence of inclusions in the metals casting industry has been controlled through:

- the use of teapot or bottom-pour ladles;
- improved pouring basin design;
- the use of slag traps, spinners and strainer cores.

Filters, in the form of woven refractory glass cloths or ceramic units (foam or cellular), have revolutionised the approach to methoding, although their use must always be considered against the increased purchase and handling costs involved.

Ceramic foam filters (Fig 12) are the most efficient, having an open-pore, reticulated structure with a porosity in excess of 90% and very high surface area to trap inclusions. The metal takes a tortuous path through the filter, effecting the removal of very small inclusions by attraction and adsorption to the internal ceramic pore surfaces.

Ceramic cellular filters have a 'honeycomb' structure comprising square section passages (Fig 13) and, because the ceramic walls are thin, can have up to 75% open area; even so, they tend to be less effective than ceramic foam filters.

Fig 12 Ceramic foam filters

The filters are positioned in the gating system so that the metal has to flow through them. A print is incorporated into the gating system to form a cavity for the filter. Cellular filters have tightly controlled external dimensions that must accurately fit the print.

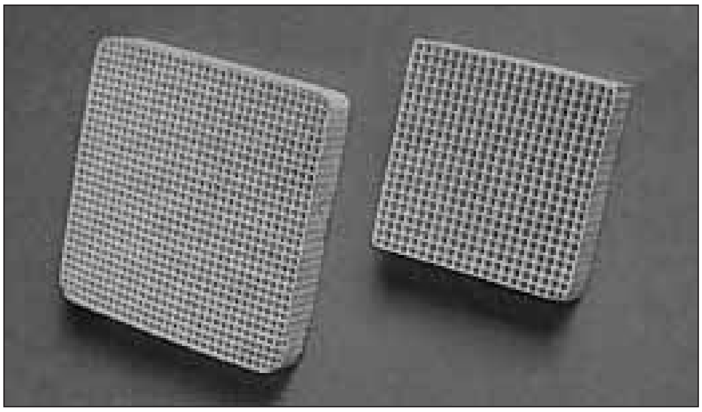


Fig 13 Ceramic cellular filters

Choice of location is the same for cellular and foam filters (Fig 14 shows possible filter positions). To function effectively, the filter should not restrict the metal flow. Specific guidelines are provided by the various manufacturers.

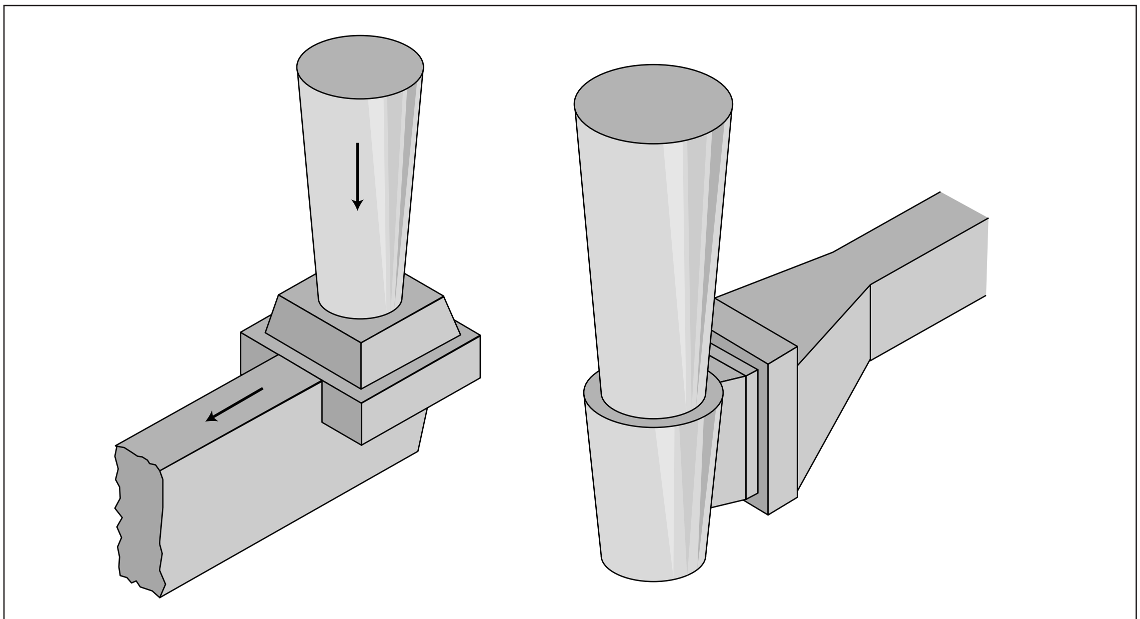


Fig 14 Filter location

In addition to acting as a trap for capturing unwanted inclusions, ceramic filters also reduce turbulent flow. As a result, much greater use can be made of unpressurised running systems, with consequent savings in the box weight leading to increased yield. The simpler running systems that can be developed with ceramic filters sometimes permit extra castings to be produced within a given moulding box, again resulting in an improved box yield.

Filters certainly have their place. However, they risk becoming the panacea for all problems and, consequently, less attention is paid to producing a running system that can function effectively without a filter.

Further information can be found in Good Practice Case Study 353, *The use of filters in ferrous foundries*.

2.2.8 *Pressure Relief Flow-off (Vent/Whistler)*

Flow-offs provide pressure relief for the gases evolved during pouring, and can be used to flush metal from a particular part of a casting. While such devices are necessary, in some circumstances they can reduce the box yield significantly. Fig 15 shows how an excessively large head on a flow-off can be reduced in size. As a result, a metal saving of 2.2 kg was achieved, without decreasing the effectiveness.

Fig 15 Effect of reducing the volume of a pressure relief flow-off

2.2.9 *Gating Ratio*

The relative cross-sectional areas of sprue, runner and ingates are defined as the gating ratio, as shown in Fig 16.

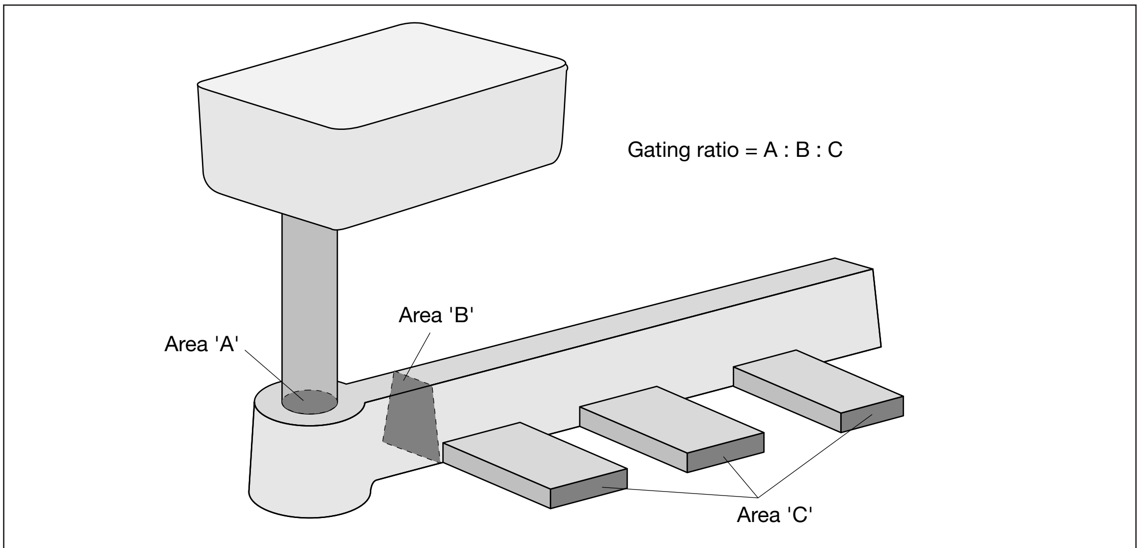


Fig 16 The gating ratio

Iron castings are commonly produced using a pressurised running system in which the total cross-sectional area of ingates is less than the cross-sectional area of the sprue, i.e. the ingates act as a choke. This system tends to provide greater protection against slag entering the mould and gives a uniform flow. However, it also promotes higher metal velocities entering the mould cavity, thereby producing a greater risk of erosion and turbulence.

While reducing metal velocities, the unpressurised system tends to hinder uniform flow, possibly causing incomplete filling of the running system and leading to dross defects. Unpressurised running systems generally require larger ingates, which are more difficult to remove during subsequent fettling.

2.3 Feeding Practice

2.3.1 *The Purpose of Feeders or Risers*

A feeder or riser provides a casting with a reservoir of molten iron to compensate for the following:

- liquid shrinkage during cooling;
- shrinkage during solidification;
- movement (dilation) of the mould walls.

The feeding requirements for small castings are normally met through the ingate system, but on larger castings it is necessary to provide an additional metal supply.

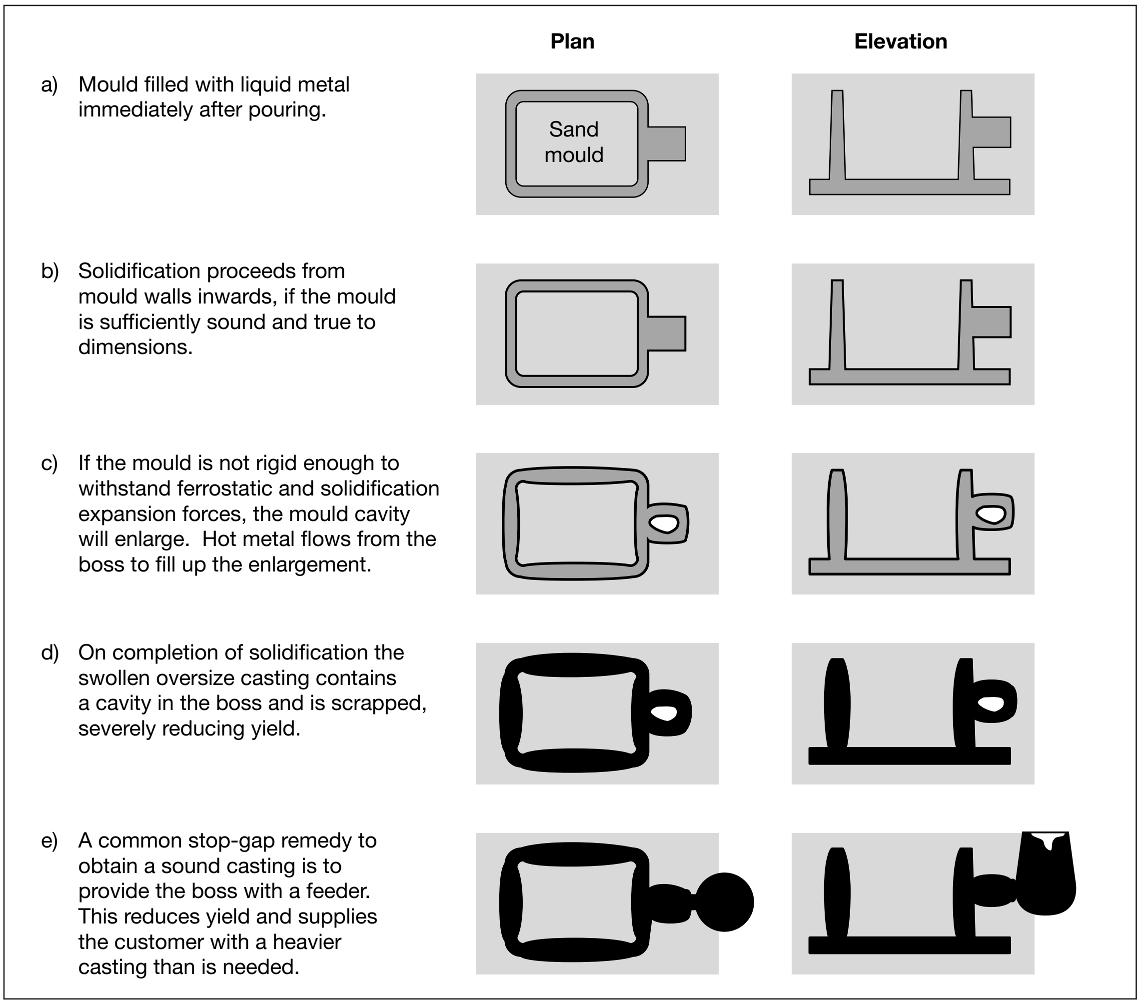


Fig 17 Rigid moulds improve yields

The progress of solidification in a casting is governed by its section thickness, and the shape of the external surfaces of the cores and the internal surfaces of the mould. The shape of the sand walls affects the heat extraction rates, particularly in respect of any corners and re-entrant angles. The use of chills or denseners also affects the local heat removal rates from the casting.

When graphite is precipitated from liquid iron at the eutectic temperature in flake and ductile irons, a considerable volumetric expansion occurs. In a rigid mould, this can be advantageous as it will facilitate the production of castings with the minimum of feed metal requirements (Fig 17). However, in the case of ductile iron, graphite expansion may cause wall dilation in soft moulds. This will result in not only dimensional inaccuracy but a requirement for additional feed metal to achieve soundness.

In high-volume foundries where good controls exist, the running and feeding systems can be refined until sound castings are made with only small margins of safety used to maximise box yield. However, foundries that operate in the jobbing market, particularly where process controls are limited, must allow greater margins of safety in the design of running and feeding systems.

2.3.2 *Feeder/Riser Design*

As the name suggests, 'feeders' feed metal into the casting body as the latter cools and shrinks; thus helping prevent defects. Feeders moulded from the same material that forms the mould for the casting (usually sand) are known as natural feeders. A correctly dimensioned feeder in a sand mould has a characteristic solidification pattern, as shown in Fig 18. The shrinkage cavity is in the form of a cone, the volume of which represents only about 14% of the original volume, some of which has been used to supply the feeder itself. In practice only about 10% of the original metal in the feeder is used to actually feed the casting.

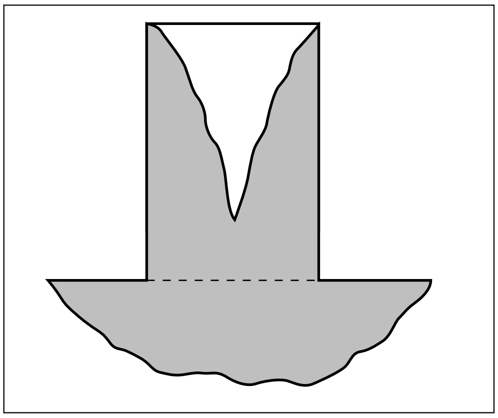


Fig 18 Characteristic solidification pattern in a sand feeder head

Two basic designs are in use, namely the 'top' and 'side' feeder, the choice depending on the particular design of casting being considered. Feeders may be open- or closed-topped (blind). They may also be 'gated through' or 'dead', depending upon whether the poured metal passes into the feeder before entering the casting cavity, or flows through the casting cavity and into the feeder. The latter situation provides colder feed metal than would be the case for the 'gated through' situation.

Feeders must have a high volume-to-surface area ratio because the metal cools principally through contact with the sand surface surrounding them. While, in theory, a spherical feeder is more efficient, a vertical cylinder with hemispherical ends is usually the most practical shape for moulding purposes. As a general rule, the feeder height should be equivalent to 0.5 - 2.0 times its diameter, head height permitting.

2.3.3 *Feeding Aids*

To maximise efficiency, the neck of the feeder (where it joins the casting) should always be kept short and never longer than half the diameter of the feeder. The shape of the neck is also very important as this area must not freeze before the feeder has completed its task. Breaker (Washburn or 'knock-off') cores are frequently located at the base of feeders to reduce the size of the feeder-to-casting interface, thereby aiding their removal, without affecting efficiency.

In addition to using plain feeders, many foundries use insulating sleeves to reduce the rate of cooling of the metal. Exothermic sleeves and hot-tapping compounds are also used where heat is generated by chemical reaction to keep the metal hot for a longer period.

If, by the use of 'feeding aids', the rate of heat loss from the feeder can be slowed down relative to the casting, then the solidification of the feeder will be delayed and the volume of feed metal available will be increased. The characteristic, conical shape of the feeder shrinkage cavity will also change and, in the ideal case, where all the heat from the feeder is lost to only the casting, a flat solidification pattern will be obtained (Fig 19).

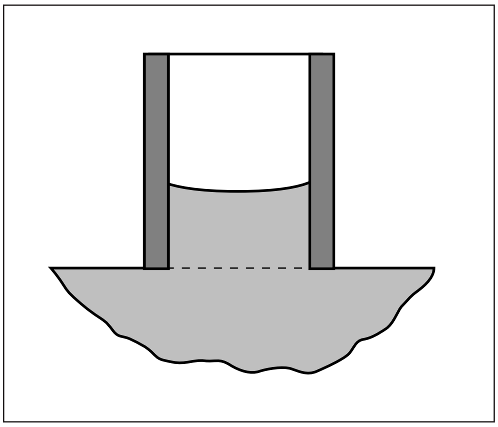


Fig 19 Optimum solidification pattern resulting from the use of 'feeding aids'

As much as 76% of an 'aided' feeder head volume is available for feeding the casting compared with only 10% for a natural sand feeder. This increased efficiency means greatly reduced feeder dimensions can be used, providing improved casting yield.

The cost of riser removal may also be reduced if smaller heads are used. However, the advantage of any feeding aid must be weighed against the purchase price and the additional moulding and handling costs involved.

2.3.4 *Polystyrene Preforms*

In some circumstances, the use of foam polystyrene preforms for certain components of the running and feeding system can improve yield. Fig 20 illustrates a white iron casting moulded with a large open-topped feeder on a central boss. This was subsequently replaced with a blind spherical polystyrene foam preform. The sphere is an ideal shape for a feeder but it is difficult to mould from a conventional pattern, hence the prevalence of tapered cylindrical shapes. The polystyrene preform feeder contained 0.73 kg of molten metal compared to 3.5 kg in the original open feeder.

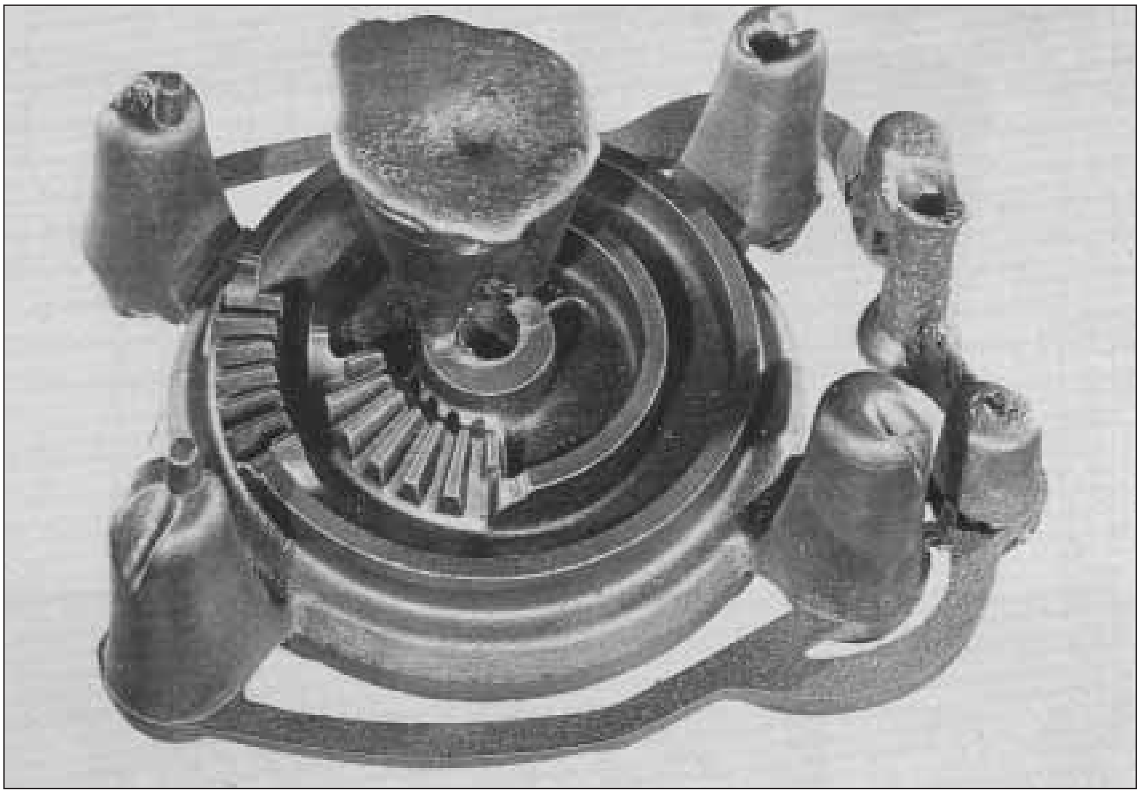


Fig 20 Use of conventional open-topped feeder

2.3.5 *Riserless Castings*

With certain larger ductile iron castings, advantage can be taken of the considerable expansion that results from graphite formation during solidification. This eliminates the necessity to employ feeders, yet ensures the production of sound castings, thereby achieving a markedly improved yield. Although the technique requires careful control and a considerable degree of confidence, it has now been adopted in a number of foundries. In order to achieve success, certain prerequisites are necessary:

- the iron must be of eutectic composition, namely a carbon equivalent liquidus value (CEL) of 4.25;
- a low pouring temperature to minimise liquid shrinkage;
- hard moulds with a high sand-to-metal ratio;
- a high pouring rate through narrow ingates;
- well-vented moulds to facilitate a rapid fill;
- rigid moulding boxes (preferably bolted together);
- well-weighted moulds.

2.3.6 *Conical Feeders*

Traditional feeder shapes with a flat or hemispherical top occasionally prove unreliable when used on iron castings, particularly ductile iron. This is due to the difficulty in establishing correct thermal gradients within the body of the feeder. The thin skin that forms at the feeder surface shortly after the completion of pouring is plastic, and not easily punctured by atmospheric pressure. Subsequently, a vacuum is formed within the feeder which inhibits metal flow to the casting.

Compared to conventionally shaped feeders, a tall, conical or tapered feeder increases piping reliability and casting yield.

Conical feeders have a very small upper diameter. Piping from the upper surface can potentially start very shortly after the completion of pouring. This is due to the volume reduction caused by initial chilling of the metal at the mould interface. It is important that the feeder is isolated from the sprue as early as possible after the completion of casting to avoid the possibility of the pouring bush supplying the initial feed demand and keeping the feeder full. This is achieved by the use of thin and/or multiple ingates that have a very short freezing time. Designing ingates with a width-to-thickness ratio greater than 5:1 will usually achieve this objective.

Fig 21 provides a schematic diagram of a conical feeder

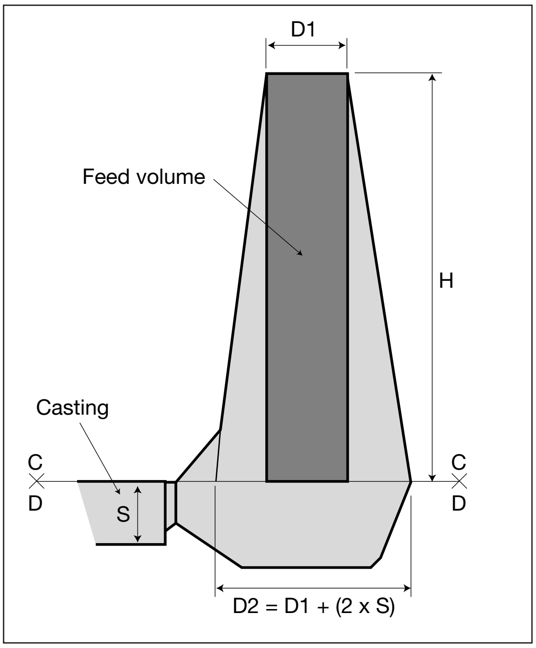


Fig 21 The conical feeder

The upper diameter of the tapered feeder (D1) should be 10% larger than the sprue diameter and is the starting point of the design. The pipe, or available feed metal, is assumed to be a cylinder of diameter equal to D1. Therefore, feeder height (H) is determined by the volume of feed metal required by the casting. For ductile iron, this is typically 2 - 5% of the poured weight, depending mainly on chemical composition, pouring temperature and mould rigidity. Conical feeders will typically be taller than conventional feeders and should extend beyond the uppermost part of the casting. The lower diameter of the tapered feeder (D2), can be simply taken as D1 plus twice the casting section at the point of contact. The design is completed by connecting the diameters of D1 and D2 with a straight line.

2.4 Computer Aids to Methoding

Computer-based products specifically designed for foundries have been in existence for several years. The earliest, and still most widely used, are programs that enable the calculation of feeder head sizes and casting weights, e.g. Crusader, Cavalier and Feedercalc. The next generation of programs began to simulate or emulate the solidification process, and notable success, as achieved by such programs as SOLSTAR, AFSOLID, PROCAST, SIMTEC, SIMULOR and MAGMASOFT. The programs have tended to be characterised as either those that are primarily knowledge-based, e.g. SOLSTAR, and those that employ heat transfer and, in some cases, fluid flow calculations in combination with ‘interrogation’ facilities.

The knowledge-based, or empirical programs, tend to be faster in overall operational terms, can be run on personal computers, and are sometimes more ‘user friendly’. However, they have limited accuracy and a reduced data input, which, in turn, restricts information output. The empirical group of programs can be either 2D or 3D. In practice, it is usual for the foundry to input data directly from a 2D hard copy drawing supplied by the customer, as opposed to working with prepared 3D digital information.

The non-empirical programs:

- offer solutions to the problems of fluid and heat flow;
- require thermophysical data input for both the casting alloy and mould;
- need a greater data input, but give greater information output;
- tend to be slower;
- can be more costly and require workstations rather than desk-top personal computers.

These programs are mostly 3D. Data input can be from 2D drawings or 2D/3D digital information. In practice, it is common to use the ‘solid modelling’ facilities, which are inherent in the programs, in conjunction with 2D drawings.

The most important distinction between empirical and non-empirical ‘fundamental’ programs is related to the data output. The non-empirical systems can give more comprehensive data than the empirical programs. However, both types of program make a valuable contribution because they enable rapid iterative or ‘what-if’ investigations to be done by the foundry methods engineer prior to pattern or tooling production.

Considerable advances are being made in the field of software development and application, thus enabling:

- optimum design for performance using advanced finite element sparse-matrix solving techniques for both static and dynamic applications (Fig 22);
- design optimisation for highest quality at lowest cost using the latest casting process simulation software (Fig 23);
- fast and accurate pattern and tool manufacture using 3D surface modelling and solid modelling software for one-off or small-batch prototype casting production (Fig 24).


Fig 22 Establishing stress distributions for performance compliance using finite element analysis

It is now well-proven that this type of service can deliver casting integrity with significant cost/weight savings, benefiting both the castings

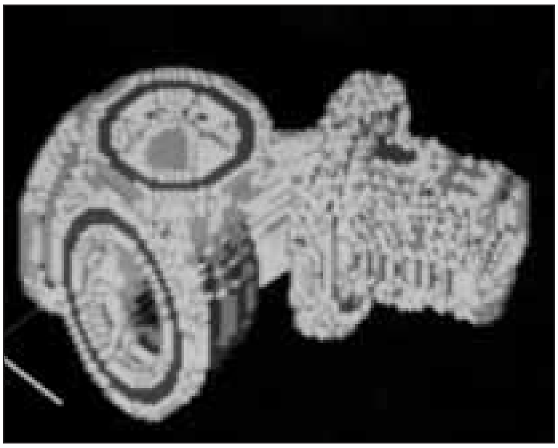


Fig 23 Software simulation of casting process

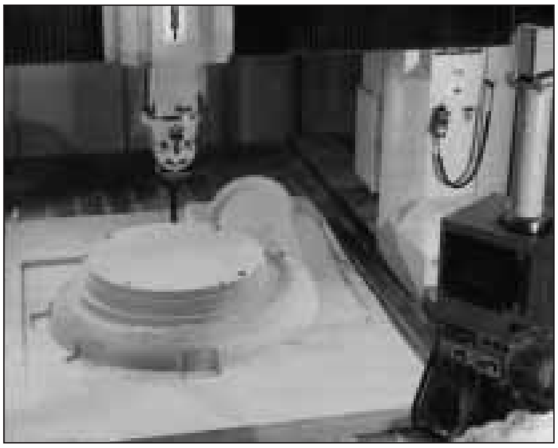


Fig 24 DNC machining of pump volute pattern

producer and customer. Furthermore, the ability to produce prototype castings on a 'right-first-time' approach also significantly enhances yield.

For additional information on this topic, Good Practice Case Study 37, *Computer simulation of solidification in ferrous foundries* and Good Practice Case Study 131, *Computer simulation of solidification in steel foundries*, should be read.

2.5 Other Considerations

2.5.1 *Modified Casting Design*

Before developing a method system it is always worth considering whether feeding specific areas of the casting could be dispensed with if the design of the casting was modified to avoid, for instance, a marked change in metal section. Fig 25 shows how a heavy section has been eliminated through improved casting design. However, this practice necessitates co-operation between the casting supplier and the customer.

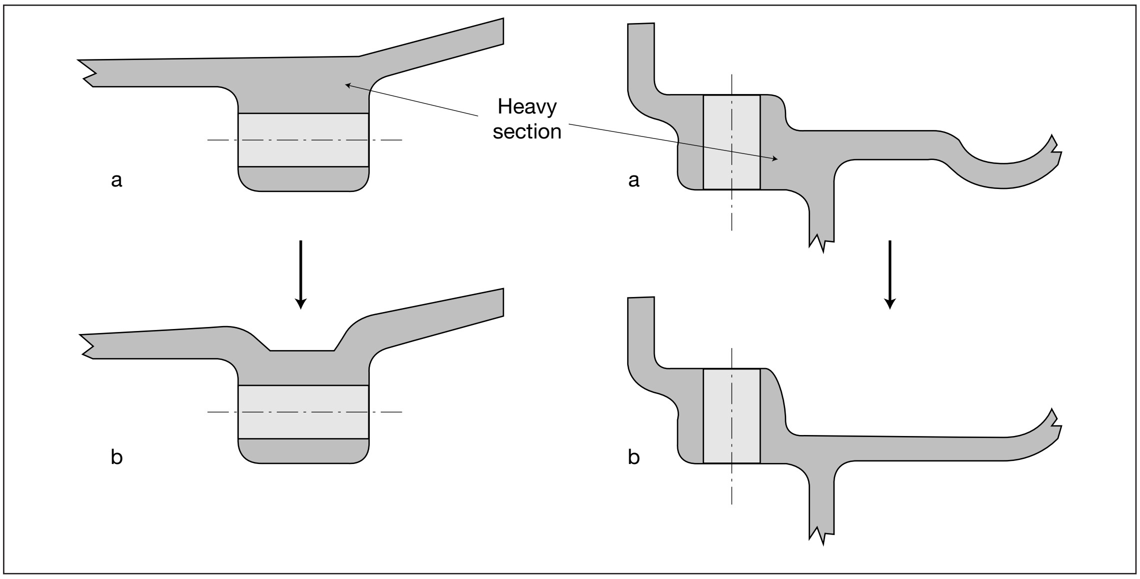


Fig 25 Examples of improved casting design

2.5.2 *Maintenance of Patterns*

The running systems on patterns must be properly maintained and reviewed each time the pattern is taken out and brought back into service. Fig 26 shows how a running system can become out-dated and lose its yield efficiency. Pattern plates are frequently modified to suit changing requirements and, all too often, the running systems are left with unwanted appendages which are never removed, thereby reducing casting yield.

2.5.3 *Records*

To obtain high box yields it is important that the poured weights are recorded on foundry job cards, a task frequently overlooked - even in otherwise efficient foundries. A suitable record system would highlight poor yields obtained on individual castings.

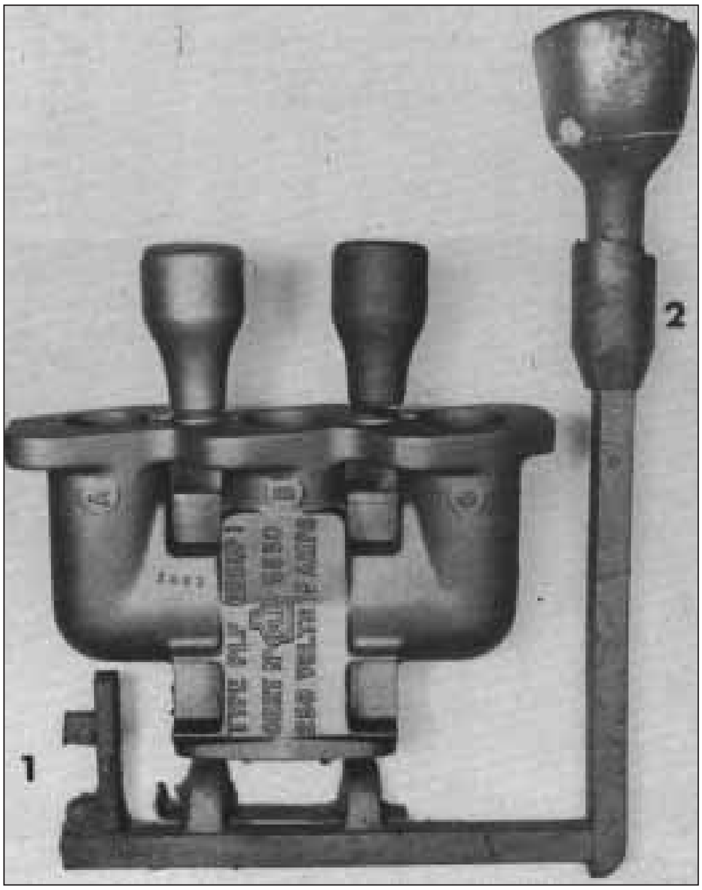


Fig 26 Unrequired pattern appendages at positions 1 and 2

KEY POINT CHECKLIST

- Examine ways of maximising box yield.
- Employ a sound approach to methoding to improve both yield and casting quality.
- Investigate the use of feeding aids or conical feeders as a means of increasing yield.
- Consider whether large ductile irons could be produced without feeders.
- Evaluate the advantages of design optimisation through the application of finite element analysis and solidification simulation techniques.
- At the earliest opportunity, always discuss with a customer the advantages of any potential design changes that will enhance casting integrity and service performance.

3. MELTING, HOLDING AND METAL DISTRIBUTION

This section examines the areas of melting, holding, metal distribution and ladle practices, showing that the efficient management of melting and pouring operations is essential to the achievement of a high yield.

Listed below are EEBPP publications relevant to the topics under discussion. Copies are available, free of charge, from ETSU Enquiries Bureau (see rear cover of this Guide).

- Section 3.1.1 GPG 58, *Cupola melting of cast iron in iron foundries*
- Section 3.1.1 GPCS 161, *Cupola melting of cast iron*
- Section 3.1.2 GPG 50, *Efficient operation of coreless induction furnaces*
- Section 3.1.2 GPCS 213, *Demonstrating good practice in medium frequency coreless induction furnaces*
- Section 3.1.2 NPCS 105, *Efficiency meter provides savings for an induction melting foundry*
- Section 3.1.3 GPG 68, *Electric holding of hot metal in iron foundries*
- Section 3.1.4 GPG 49, *Energy efficient ladle preheating techniques within the steel industry*
- Section 3.1.4 GPG 63, *Metal distribution and handling in iron foundries*

3.1 Overview

Approximately two-thirds of the energy used in an average iron foundry is consumed in metal melting and holding operations. While a finite quantity of energy is required to melt and superheat the molten metal to a suitable temperature for casting, all other energy inputs and losses are within the control of the foundry.

In many cases, excess melting energy, in the form of superheating, is used to compensate for inadequacies in the subsequent molten metal handling and distribution systems. While some losses are inevitable, considerable energy savings can be achieved by proper attention to processes and handling systems, together with good operational practice and equipment maintenance. Consequently, many molten metal handling systems waste energy, manpower and space, and give rise to a high proportion of the foundry's scrap.

3.1.1 *Cupola Melting*

The melting of iron is principally carried out in either cupola furnaces or coreless electric units. In 1997 in the UK, approximately 1.0 million tonnes of cast iron were melted in cold-blast cupolas and a further 0.3 million tonnes in hot-blast cupolas. These operations involve burning 225,000 tonnes of coke (equivalent to 337,000 tonnes of coal) at a cost of approximately £34 million, resulting in 800,000 tonnes of CO_2 emissions. It is estimated that 8 - 12% of the energy used could be saved, and therefore pollution reduced, through the adoption of good practices.

Most modern, high-output cupola melting systems have computerised charge-weighing and recording systems. Some of these incorporate facilities for modifying the charge mix depending on the requirement. Some advanced cupolas also use computerised monitoring systems that react to significant changes in operating parameters, e.g. combustion ratio, blast temperature, windbelt pressure, tapping temperature, etc. Currently, there are no comprehensive computerised control loop systems commercially available that can automatically control cupola operating parameters fully, in both predictive and reactive modes.

As yet, no application is known where model data is used as a basis for 'real time' control of a cupola melting system. Such a system would require active feedback of measured operating data to form the basis of a control loop. Interfacing with cupola charging, blast control and the iron

metallurgy requires considerably more research and development. ‘Real time’ computerised control for cupolas must be developed if integrated melting systems are to be operated to their full potential, but these are likely to be ‘bespoke’ systems for specialised applications.

3.1.2 *Electrical Induction Melting*

In the case of electric melting, a typical coreless furnace can melt a tonne of iron and raise the temperature of the liquid metal to 1,450°C using under 600 kWh of electricity. However, in practice, relatively few foundries achieve this level of specific consumption on a week-by-week basis. Some foundries consume as much as 1,000 kWh for every tonne of iron produced in their coreless furnaces. It is estimated that approximately 800 kt of iron were melted in coreless induction furnaces during 1997 at an energy cost of £27 million. As with cupola melting, it is anticipated that between 8 and 12% of current usage could be saved through better operating practices.

Clearly, while all inefficiencies in the melting operation must be addressed as a function of sound management practice, any opportunities to increase the overall casting yield will result in a lower metal melting requirement and, hence, lead to significant cost savings. Similarly, improved yield will allow the production of more saleable castings from the same quantity of molten iron melted previously.

Electric melting operations should be closely monitored, and easily assimilated graphical displays provided to indicate undesirable trends in power consumption and consequent costs to both management and shop floor operators.

Computerised energy management systems should be considered when installing any induction furnace system (Fig 27). These will assist not only in establishing good melting practice, but with economical fritting and cold-start operations.

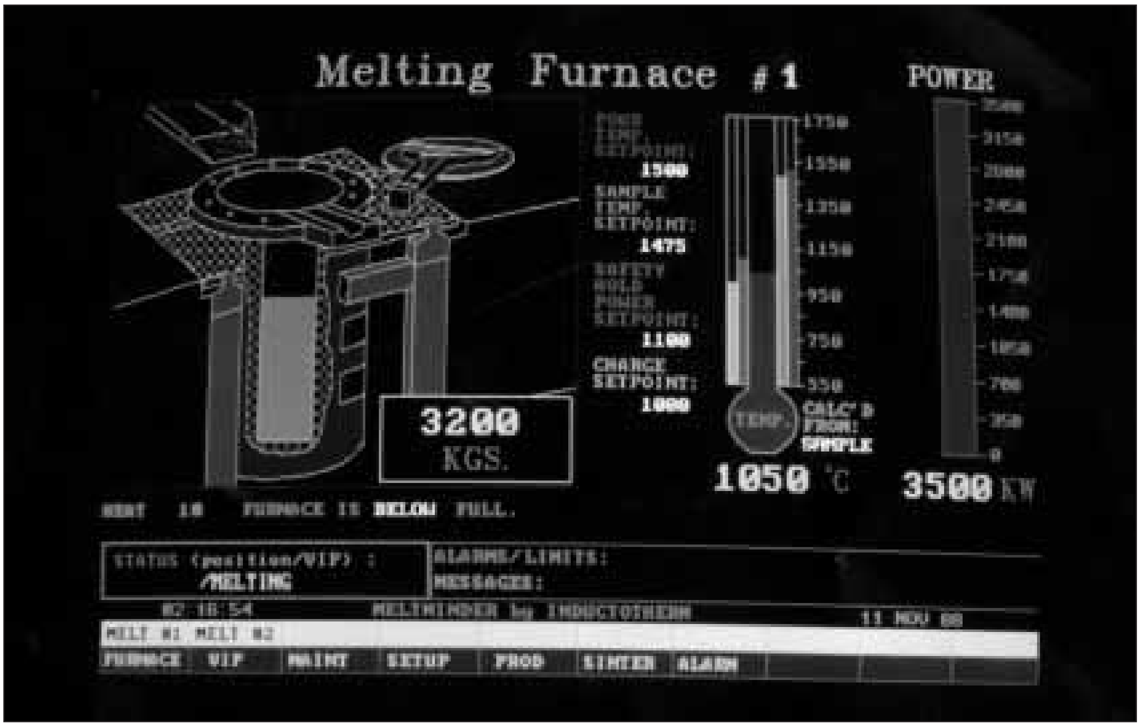


Fig 27 Typical furnace screen from a computerised energy management system

Most furnace suppliers now offer computer-based data analysis and display systems to control and monitor the performance of coreless furnaces and assist in efficient furnace operation. These systems generally provide data displays in graphical and tabular form on a PC screen.

The following aspects of electric melting are well-suited to the application of computer control:

- status of melt - weights
  - power levels
  - temperature estimates
  - set points for weights and temperatures;
- operating parameters of the power supply;
- sintering cycle and cold start-up operations;
- alarms;
- maintenance parameters - critical temperatures, lining condition;
- productivity data - date, time, shift, tonnage, electricity consumption, breakdown delays;
- charging details - availability of charge materials
  - status of charging system
  - charge mixtures
  - composition of charge materials
  - material usage and stock control.

Programmable logic controllers transmit data to the computer software. The data can then be presented to the user in various modules, e.g. it can be stored, tabulated or graphically displayed.

3.1.3 *Holding*

Many large and medium-sized foundries employ mechanised methods of mould production which require a continuous supply of molten metal. Demand often fluctuates during the day and a buffer supply of molten metal is considered advantageous. It has become established practice in some foundries to use electric channel or coreless furnaces to hold, superheat, and adjust the composition of molten iron from both cupola and primary electric melting furnaces.

Intermediate holding and superheating furnaces, particularly those of the channel induction type, require a constant supply of energy merely to maintain a uniform bath temperature. Continuous holding of metal is expensive, particularly in single shift operation. Furthermore, additional maintenance and relining costs can be high. Large holding units are only suitable for foundries producing a limited range of metallurgical specifications or where a common base material can be used. In a similar vein, many of the automatic pouring furnaces used in iron foundries have a similar basic design to electric channel furnaces, and have a role as holding furnaces.

3.1.4 *Metal Distribution*

All iron foundries, irrespective of their size, product range, methods or processes used, need to transport molten metal, sometimes over considerable distances, to the various pouring stations. There is often a need for intermediate treatments to be carried out, together with sampling and testing procedures, all of which take time and increase temperature losses. The result is an increased risk of reject castings being produced.

Furthermore, metal distribution involves the use of ladles, which require effective lining installation, preheating, handling and maintenance if energy is to be conserved and defective castings, hence reduced yield, avoided.

Ladle Practice

Three main forms of ladle are used for pouring iron castings: lip-pour, drum and teapot spout.

With the lip-pour and drum ladles, the metal is discharged over the lip and the flow is controlled by tilting the ladle, using a geared handwheel. Because the metal flows from the top of the ladle, its surface must be slag-free, or a skimmer should be used to prevent slag entering the mould. Lip-pour ladles are ideal for handling small quantities of metal and are easy to prepare. The disadvantage is that slag can easily be entrained in the metal stream.

In a teapot spout ladle, the provision of a refractory dam before the ladle lip ensures that slag-free metal is drawn from the bottom of the ladle. Deoxidation products have more time to float away from the area where metal is being withdrawn, so the iron is generally cleaner than from a lip-pour ladle. The disadvantage is that the narrow 'spout' may cause the liquid metal to freeze if pouring is prolonged.

Both lip-pour and teapot spout ladles must be inverted to remove all slag and metal before refilling or reheating.

Traditionally, all but the largest iron foundry ladles have been lined with ganister, naturally bonded sand or firebrick, or a combination of these materials. When they are of good quality and used correctly, these materials are still suitable for many applications and have a low initial cost.

Recently, there has been increased interest in more durable refractory lining materials that provide better insulation against both conducted and radiated heat losses. Alumina-based refractory materials are now available in plastic and castable form. These provide highly refractory and mechanically strong linings, but are expensive and need skilled installation to achieve the best results. Special formers are needed if castable materials, including those requiring vibro-compaction, are used. Preformed ladle linings and sectional refractory board materials for ladle lining have also been developed. The latter have been put to considerable use in steel casting but are not yet widely used in iron foundries.

Heat losses from ladles are partly related to the ratio of the exposed molten metal surface to its volume. For this reason, heat losses from drum ladles, which have a more closed construction, are not, in practice, less than those from bucket ladles fitted with a lid. When full, the metal level in a drum ladle is only just above the centreline, so the surface to volume ratio is high. The worst heat losses from ladles occur when the ladles are filled for the first time after preheating or when they are only used intermittently. With continuously used ladles, temperature losses will stabilise at a predictable value.

3.2 Factors Influencing Yield

The main factors affecting yield are generally related to the following:

- melting losses caused by oxidation;
- pigged metal that is either surplus to demand or metallurgically unsatisfactory;
- scrap castings resulting from deficiencies in the melting and pouring operation;
- metal spillage during distribution and pouring.

3.2.1 *Reducing the Melting Losses*

Melting losses represent the difference between the weight of metal charged into the furnace and the weight of molten metal tapped. The extent of such losses depends largely on both the condition of the charge materials and the furnace operating practices, and should not normally exceed 2%. Melting losses include weight losses due to oxidation, metal removed for test pieces, incidental loss of metal during slag removal operations and the dropping of cupola bottoms, and apparent weight losses due to extraneous non-metallic materials being included in the weighed furnace charges. These melting losses are small compared to the weight of material used in running and feeding systems but are, nevertheless, important and should be carefully monitored.

Table 2 highlights the actions that should be considered for furnace operation.

Table 2 Actions to reduce melting losses

Good practice	**Cupola**	**Electric furnace**
Avoid the use of contaminated charge materials	*	*
Weigh **all** charge materials and maintain records	*	*
Set and control the optimum blast rate	*	
Ensure good coke-bed preparation	*	
Use coke of correct size and composition	*	
Maintain the cupola full during the blow	*	
Avoid intermittent blast or reduced blast operation	*	
Control oxygen levels (if applicable)	*	
Employ efficient slagging practice	*	*
Recover metal from cupola drop	*	
Avoid unnecessary superheating	*	*
Maintain good lining repair	*	*

3.2.2 *Reducing the Quantities of Pigged Metal*

Liquid metal that is unsuitable for pouring purposes, due to unsatisfactory composition or low temperature, must be pigged. If it is poured into moulds, the scrap that is likely to result will entail far more expense and wasted energy than that needed to re-melt the pigged metal.

The foundry should avoid excessive pigging of metal; while 0% would be ideal, a target of less than 5% would be more realistic. If the amount of metal pigged is too great or if it appears to be increasing significantly, the melting operation should be reviewed to identify ways and means of achieving a reduction.

In addition to metal of unsatisfactory quality, a proportion of metal is frequently pigged due to a lack of balance between demand and melting rate. When the amount becomes significant, the situation should be investigated and remedial action taken.

To control the volume of metal that has to be pigged, attention should be paid to the following aspects:

Balancing Metal Demand with Melting Rate

As far as possible, the production schedules should be organised so that the metal demand will be evenly matched to the output of the melting furnaces. In the case of cupola melting, if there is a consistent excess of molten metal produced compared with demand, the diameter of the melting zone and the air blast rate should be reduced accordingly to satisfy the lower level of demand more efficiently.

Avoiding Plant Stoppages

A significant stoppage on key moulding plant frequently means that the surplus melted metal will need to be pigged. Plant stoppages are usually caused by either machine breakdown or some operational difficulty, e.g. lack of suitable cores. Delays should be monitored to establish the principal reasons, and actions taken to reduce these stoppages as part of a planned preventive maintenance programme.

Providing Metal at the Correct Temperature

There should be no problem with supplying metal at the correct temperature from electric induction furnaces. The control of metal temperatures is relatively simple since the batch type of operation allows for temperatures to be readily adjusted prior to tapping.

In contrast, the frequently intermittent operation of the cupola furnace makes temperature control much more difficult unless some form of holding/superheating furnace/receiver is provided. Invariably, low metal temperatures will be obtained early in the melt. When lengthy stoppages occur, due to plant breakdowns or overproduction of metal in relation to demand, metal temperatures from the cupola furnace will be depressed (Fig 28) as a consequence of the blast shut-off periods. In this context, the use of oxygen enrichment on cupolas can be of great benefit in both raising metal temperatures rapidly and reducing coke usage.

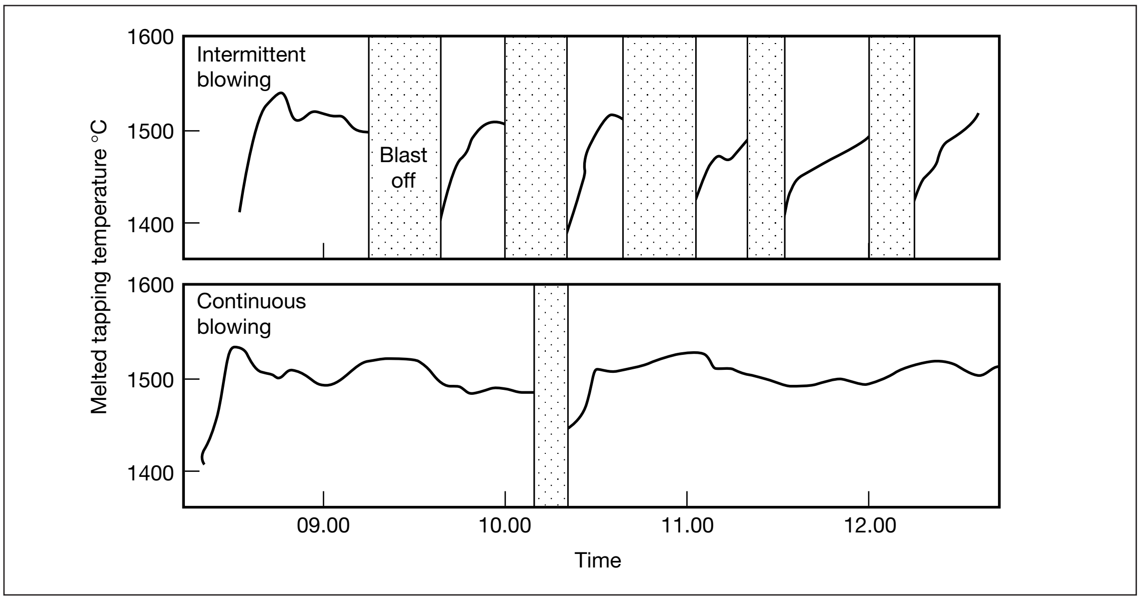


Fig 28 Effect of blast shut-off periods on tapping temperature of cupola-melted metal

In some foundries, particularly at the commencement of the melt, low-temperature metal can be poured into non-critical moulds, thus reducing the quantity of metal which has to be pigged.

Obviously, a cupola should always be operated at its optimum blast rate and coke charge if efficient melting is to be achieved.

Use of Holding Furnaces

Holding furnaces, particularly those with a capability to maintain or even superheat metal from a primary melting facility, can markedly enhance yield by reducing the production of defective castings caused by incorrect temperature and composition, and decreasing the amount of pigged metal.

Holding furnaces, principally electric coreless or channel units, fulfill one or more of the following functions, depending on the requirements of a particular plant:

- Provide a reservoir of molten metal to cater for variations in plant demand, allowing a certain amount of operational independence from the primary melting furnace.
- Make available a buffer capacity of molten metal to enable efficient use of the primary melting system. Coke consumption can be reduced when a cupola is operated continuously and independently of demand variations.
- Superheat molten iron after intermediate metal treatments have been carried out, e.g. desulphurisation.

- Even out compositional variations in the metal received from the primary melting unit and allow compositional adjustments to be made.
- Enable metal to be supplied to the moulding line when required, thus reducing waiting time and production losses and overcoming problems associated with a breakdown in another area of the foundry.

Hot Metal Receivers

Hot metal receivers are frequently used in conjunction with cupola melting operations and may be heated or unheated.

Unheated receivers, whether in the form of large ladles or specially constructed vessels, are generally unsatisfactory. Heat losses are high and satisfactory metal temperatures cannot be maintained, except by excessive superheating in the primary melters. Therefore, no form of unheated unit is recommended for use in a modern foundry.

Heated receivers are generally fuel-fired by either oil or gas. While fuel-fired hot metal receivers are relatively cheap to install, maintain and operate, they generally have a low fuel efficiency. Higher gas and oil costs have led to a decrease in their use. Superheating is not possible unless a rotary-type furnace is used. Oxidation of metal in the bath, with consequent slag build-up, can occur during long holding periods with fuel-fired receivers. Because of the problems associated with this type of equipment, they are not widely used.

3.2.3 *Reducing Scrap from Faults in Melting or Pouring Operations*

Metal of the required temperature and composition is essential for the production of saleable castings, and the minimisation of losses through the prevention of scrap is a vital step in attaining a high foundry yield. Reduced scrap not only improves yield but also reduces the energy consumed in all production departments. Good working procedures are essential in the melting and pouring departments to contain the level of foundry scrap. Careful attention should be paid to the following points:

Specification of Molten Metal

Modern analytical and control test techniques allow the suitability of the molten iron to be checked before it is poured into moulds. If it is found to be outside specified limits and remedial action is not possible, the unsatisfactory metal must be pigged.

Control of Pouring Temperatures

The optimum pouring temperature range for each type of casting produced must be established and controlled within these limits.

Energy is wasted if:

- the metal supplied is too hot and has to be cooled before pouring, to prevent defects due to internal shrinkage;
- the molten-metal transfer system allows excessive loss of metal temperature between furnace tapping and mould pouring, causing castings to be scrapped for cold-metal defects such as misruns, blows and laps.

To increase metal temperature by 50°C in an electric melting furnace, approximately 24 kWh/tonne of energy is required. To effect this in a cupola, approximately 5% more coke by weight of metal melted is consumed because the cupola is less efficient at superheating metal.

Metal temperatures are at their most critical when the last mould is being poured from a ladle. To ensure satisfactory temperatures at this point, the following recommendations should be implemented:

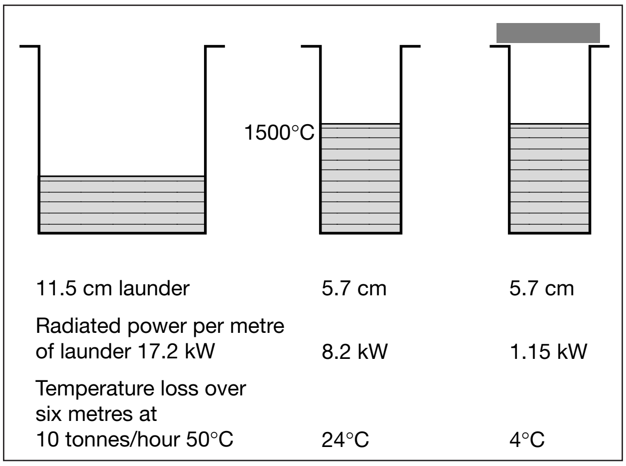


Fig 29 Heat loss from launders

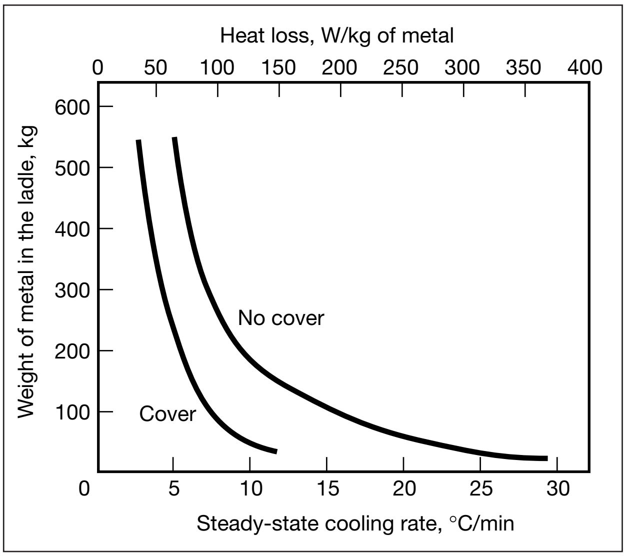


Fig 30 Cooling rate of metal in ladle

- Use a correctly sized furnace launder and ladles with heat-retaining covers - a large amount of heat can be lost from them (Figs 29 and 30).
- Use clean ladles pre-heated to bright red heat (1,000°C or more). Newly lined or patched ladles should be dried slowly and thoroughly before pre-heating. Using correctly aerated burners and heat retaining baffles for one hour is usually sufficient to achieve a lining temperature of 1,000°C.
- Keep molten metal tapping temperatures from the primary melting furnace as close as possible to the required pouring temperature, taking into account unavoidable losses, the necessity for intermediate treatments, and maintenance of the correct metal composition.
- Design intermediate treatment systems to minimise heat losses and superheating requirements.
- Avoid the intermittent use of pouring ladles; if essential, efficient ladle heating should be used, both before and during use.
- Use distribution and pouring ladles that are as large as is practicable and fitted with heat-retaining covers. Metal tends to cool faster in a drum ladle than in a properly covered bucket-type ladle because the metal surface is more exposed.
- Keep the heat-retaining covers on ladles that are standing empty and not returned to the preheaters, e.g. at break-times and between shifts.
- Minimise and, where practicable, eliminate the need to transfer metal from one ladle to another.
- Deliver the metal from the furnace to the mould-pouring station as quickly as possible, while still complying with safety requirements. Design the foundry layout to ensure that the metal supply is as near to the mould-pouring station as is practicable.
- Pour moulds as quickly as possible, thereby enabling the pouring ladles to be emptied rapidly. Slow pouring increases the risk of cold metal defects in the last moulds poured from the ladle. In volume production situations, aim to pour small moulds in about 15 seconds, or less, and all moulds, with few exceptions, in under 25 seconds.
- Monitor any action taken, as follows:
    - Measure metal temperatures at furnace tapping, ladle transfer and mould pouring. If a holding furnace or receiver is used, measure temperatures of metal entering and leaving the unit. Check the time intervals between tapping and mould pouring.

- Analyse reject casting records regularly to identify scrap losses caused by pouring metal at temperatures that are either too high or too low. Ensure control of pouring temperature within a specified range for castings that merit such action.

Controlling Metal Quantities Tapped into Ladles

It is bad practice to refill ladles which contain a residue of metal from the previous pouring cycle - surplus metal must always be pigged. To reduce the amount of surplus metal that has to be pigged, the quantities of metal tapped into a ladle should, ideally, be weighed to provide sufficient material (with a minimum excess) for pouring a given number of moulds.

3.2.4 *Metal Spillage During Distribution and Pouring*

An appreciable quantity of metal can be lost irredeemably through the careless handling of ladles, which results in metal splashes on the top of moulds, at the mould-pouring stations and on the foundry floor. Pouring moulds requires skill, judgement, good facilities and effective training.

Automatic Pouring

If spillage is excessive, the metal transport and pouring operations should be examined to establish whether the equipment and layout could be improved to simplify the operator's task.

The use of automatic pouring units in foundries has now become accepted practice in highly automated plants and may, in fact, be regarded as essential on modern moulding lines using both flaskless and conventional mould configurations. The speed of modern moulding equipment, commonly in excess of 350 moulds per hour on Disamatic type installations and 150 moulds per hour on boxed plants, effectively precludes manual pouring systems using conventional ladles suspended from overhead monorails or cranes. The organisation of such systems, particularly when meeting the requirements for sampling, quality control, and metal treatments that must be carried out in the ladle, creates logistical problems that inevitably lead to delays in production.

The installation of modern, fully automatic pouring units, of the type shown in Fig 31, can make a substantial contribution to yield. Normally, metal poured from such installations is clean and at the correct temperature, thereby reducing the incidence of scrap. Automatic pouring units can

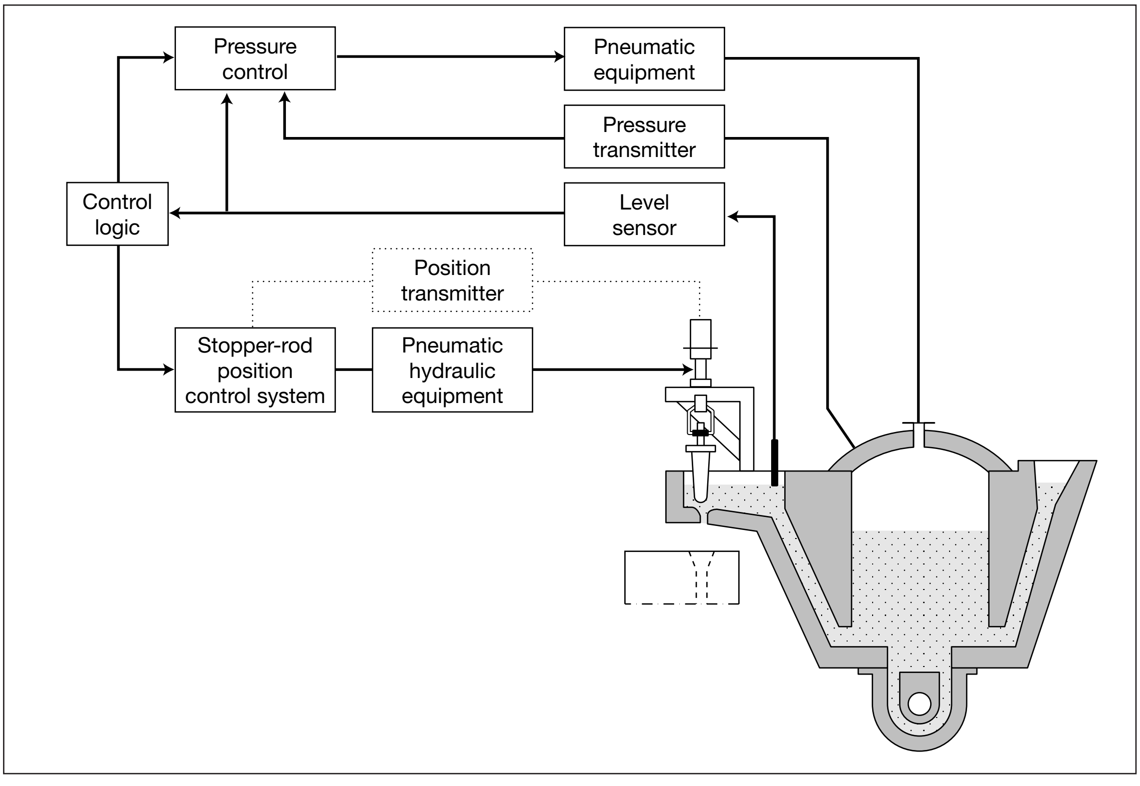


Fig 31 Schematic diagram showing an automated pressure-pouring vessel with stopper-rod and dosing control (ASEA)

be operated to provide a predetermined dose of metal for each mould, which reduces the excess quantity of metal poured to a minimum.

In many instances, the size of the pouring bush can be reduced compared to manual pouring operations; again, this may save metal. Furthermore, automatic pouring units can provide precise alignment of the metal dispensing nozzle and the pouring bush on the mould. This will reduce losses due to spillage and splashing.

The use of automatic pouring units generally results in significant overall energy savings. This is due to reduced transfer losses and improved casting yield, combined with more efficient use of the primary melting capability and improved plant utilisation.

Direct Pouring

A well-designed gating system should supply inclusion-free metal to the mould cavity and minimise turbulence. It must also regulate metal flow without eroding mould surfaces.

The gating system should be long enough to allow inclusions to float up and adhere to the top surfaces of the system. However, long gating systems are often impractical due to physical constraints and their effect on yield. They often result in cold-metal defects or the need for higher pouring temperatures.

Short running systems reduce heat losses, but also reduce the opportunity for inclusion flotation. Furthermore, they frequently create high metal velocities and turbulent flow, leading to the formation and entrainment of additional inclusions.

In recent years, ceramic filters (placed close to the mould cavity) have been used to both trap inclusions and decrease turbulent flow. However, because the first metal to reach the filter has already lost considerable heat, additional heat is needed to prime the filter and avoid the formation of temperature-related defects.

Recently, the development of direct pouring systems has opened up new possibilities to further increase yield for all casting alloys. Each unit comprises an insulating sleeve with a ceramic filter positioned at the base (Fig 32).

A direct pouring system can be applied to the production of castings in both horizontal as well as vertical machine moulding systems. These systems help ensure that there is hotter metal in the feeders than in the castings, thereby achieving directional solidification from the casting to the feeder.

Fig 32 Direct pouring system
(courtesy of Foseco (FS) Ltd)

A practical example of the application of a direct pouring system for the production of ductile iron hub castings, each weighing 7.6 kg, is shown in Figs 33 and 34. MAGMASOFT computer simulation of the mould-filling operation and solidification process predicted that all four castings could fill simultaneously, with little turbulence created in the mould cavities. The simulation confirmed that the temperature of the iron in the pouring units was higher than that in the castings and that the temperature gradient created would ensure that adequate feed metal was provided. The predicted results were confirmed in practice, the direct pouring system providing a box yield of 81.3% compared with 54.2% from the original running system, a saving of 18.6 kg of iron per mould, or 4.7 kg per casting.

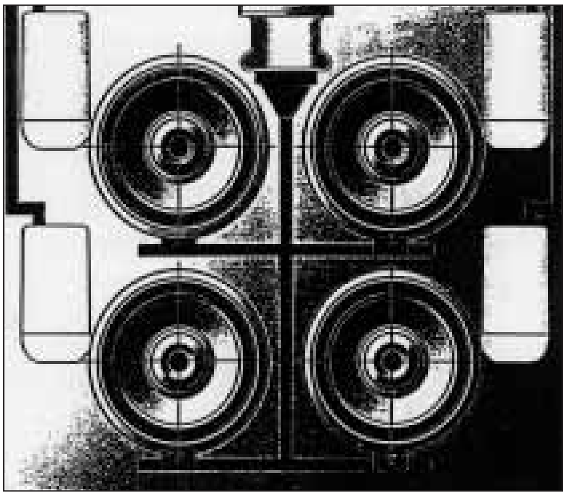


Fig 33 Ductile iron hub casting with standard running system (courtesy of Foseco (FS) Ltd)

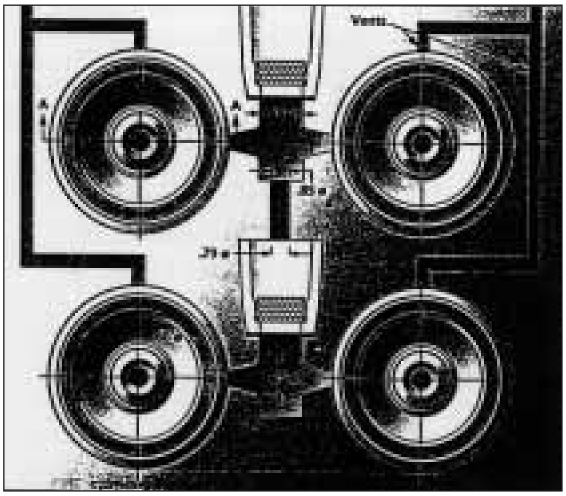


Fig 34 Ductile iron hub casting with direct pouring system (courtesy of Foseco (FS) Ltd)

KEY POINT CHECKLIST

- Operate all melting and holding plant under optimum conditions to reduce melting losses and minimise energy consumption.
- Balance metal demand and melting rate.
- Avoid unnecessary superheating of the molten iron.
- Optimise metal handling and distribution to reduce metal transfer operations, transportation distances and spillage.
- Take action to improve ladle and launder practices to minimise temperature losses and the presence of non-metallic inclusions in the resultant castings.
- Establish, monitor and control pouring temperature and mould filling rates.
- Consider the advantages of automatic or direct pouring techniques, where applicable.

4. DEFECTIVE CASTINGS AND YIELD

4.1 Overview

The manufacture of iron castings is a complex, variable operation involving many stages (Fig 35).

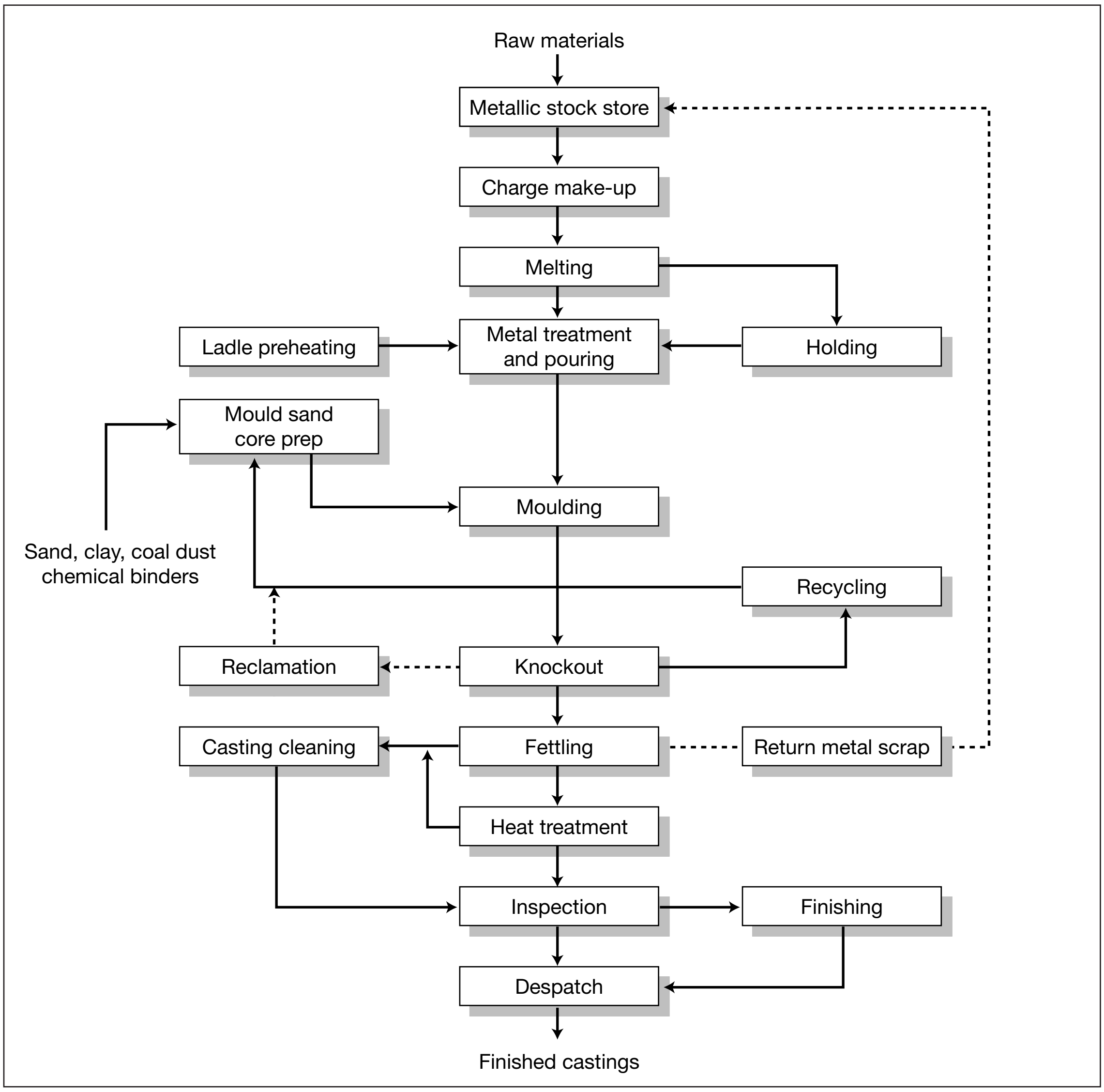


Fig 35 Ferrous foundry process route

As with any production process, some reject castings will be produced and subsequently re-melted, while others may only be detected by the customer. Unfortunately, the problems are frequently only uncovered during a machining operation, when considerable added value will have accumulated. The probability is that an entire batch of castings will be returned to the supplier. Therefore, the overall effect of defective castings is to significantly reduce yield, decrease profitability, lower productivity, and, perhaps most importantly, adversely affect customer relationships, as the parts will have to be replaced.

The reduction of casting defects is a major subject on its own. In essence, it requires the establishment and consistent implementation of quality control procedures relating to the following:

- raw materials;
- production and distribution of molten iron;
- core quality;

- mould production;
- knockout, fettling and handling;
- plant and equipment maintenance.

A guide to maintaining technical control in iron foundries is shown in Tables 3 to 8.

Table 3 Control of raw materials for melting and metal treatment

Material	**Parameters**	**Consequence of poor control**
Pig iron	Chemical composition Storage - identification and segregation	Incorrect metal composition Unacceptable mechanical properties Shrinkage porosity
Cast iron scrap	Inadequate segregation Oversize material Contamination by: - non-ferrous metals (aluminium, lead) - paint (lead) - vitreous enamel (boron, antimony) - gas works scrap (sulphur)	Incorrect metal composition Uneven melting - temperature and composition problems Pinholes (aluminium), embrittlement (lead) Cracking, loss of strength Chill, increased hardness Chilled edges, surface blows
Low carbon steel scrap	Oversize material Contamination by: - sulphur-bearing steel (sulphur) - free-cutting steel (lead) - paint (lead) - stainless steel (cromium)	Variable metal temperature and composition Chilled edges, surface blows Embrittlement Embrittlement Chill, increased hardness
Coke	Mean size < 9 cm High sulphur and/or ash content Outside storage - moisture pick-up	Low temperature, reduced melting rate Increased sulphur and variable carbon pick-up Misruns, blowholes
Non-metallics: - ferro-alloys - carburisers - inoculants	Incorrect composition Incorrect grading: - too large - too fine Storage - moisture pick-up Contamination by: - high sulphur/nitrogen gas content (carburiser) - aluminium pick-up (inoculant)	Incorrect metal composition Undissolved particles - machinability problems Low pick-up - incorrect composition Pinholes (hydrogen gas) Chilled edges (sulphur), fissures, increased strength (nitrogen gas), pinholes (aluminium)

Table 4 Control of melting and metal treatment

Material	**Parameters**	**Consequence of poor control**
Charge preparation	Inconsistent charge make-up	Variable metal composition and properties
	Faulty weighing	Temperature-related defects, internal porosity, sinks, misruns and blowholes
Cupola melting	Melting zone diameter not maintained	Variable carbon pick-up, temperature-related defects
	Poor lining preparation and drying	Pinholes (hydrogen gas)
	Poor coke bed preparation, bed height not maintained, incorrect blast volume, intermittent operation	Variable metal composition, temperature-related defects
Electric melting	Excessive superheating	Reduced nucleation and strength, shrinkage porosity
Metal treatment	Incorrect material additions	Incorrect metal composition
	Inadequate mixing	Variable metal quality
	Undissolved alloy additions	Impaired properties and machinability
Metal distribution	Unheated ladles, ladles not emptied before refilling, cold metal not pigged, pouring temperatures not controlled, long transportation distance, launder/ladle covers not used, low pouring speeds	Cold metal resulting in misruns, blowholes, dross formation, etc.
	Inadequate ladle drying, poor ladle refractories	Pinholes (hydrogen gas)
	Dirty ladles, metal not skimmed, pouring bush not kept full	Slag, dross defects
	Pouring speed too high	Sand inclusions

Table 5 Control of moulding

Material or operation	**Parameters**	**Consequence of poor control**
Sand	Incorrect grading	Blowholes, poor mechanical properties
	High acid demand value	Low strength development in acid-catalysed systems
Coal dust	Incorrect grading	Poor surface finish
	Low volatile/high ash content	Surface blows and imperfections
	Coarse particles, high sulphur content	Flake graphite skin formation in ductile iron
Greensand preparation	Sand additions not measured, milling times not controlled	Swollen castings, internal porosity, blowholes, metal penetration, broken moulds
	Insufficient input of new sand	Build up of harmful fine material
	Hot sand	Poor surface finish
Pattern equipment	Poor pattern maintenance	Dimensional inaccuracy, sand inclusions
	Inadequate temperature control	Rough mould surface, broken moulds
Moulding boxes	Poor maintenance	Cross joint, run-out, inclusions
	Inadequate strength	Springback leading to dimensional faults
	Boxes too small or too many patterns on plate	Swollen castings, shrinkage porosity
Mouldmaking	Variation in compaction	Swollen castings, internal porosity, dimensional inaccuracy, metal penetration
	Core movement, breakage and crushing	Dimensional faults, inclusions, blowholes
	Badly made running system	Sand erosion, inclusions
	Mould assembly not blown-out before closure	Inclusions
Mould closing and handling	Rough handling, pins removed before clamping or moving	Inclusions, cross-jointing, broken moulds
	Inadequate weighting	Run out, swollen castings, internal porosity
	Excessive weighting	Broken cope moulds

Table 6 Control of coremaking

Operation or equipment	**Parameters**	**Consequence of poor control**
Sand preparation	Incorrect additions	Dimensional faults, blowholes
	Mills/mixers not cleaned	Blowholes, inclusions
Corebox equipment	Dimensions and wear on dowel pegs	Dimensional faults
	Coreboxes not cleaned	Dimensional faults, rough surface
	Worn/blocked vents	Rough surface, metal penetration, blowholes
	Stripping problems	Rough surface finish
Core coating	Mixing instructions not followed, mixing equipment not cleaned, specific gravity not controlled, uneven application, coating not fully dried	Surface imperfections, blowholes, dimensional inaccuracy
Core inspection	Blocked vents, wet coating, cracks	Blowholes
	Poor compaction	Metal penetration
	Exposed wires	Fused wires
	Breakages	Excess metal
	Incorrect dimensions	Dimensional faults
	Excessive use of adhesives	Blowholes
Handling	Failure to provide racks	Damaged or broken cores - fins and blowholes
Storage	Temperature, humidity	Blowholes

Note: Advice relating to the control of the five main binder systems (excluding greensand) is published in the Environmental Technology Best Practice Programme's Good Practice Guide (GG) 104, *Cost-effective management of chemical binders in foundries*, copies of which are available, free of charge to UK businesses, through the Environment and Energy Helpline on 0800 585794.

Table 7 Maintenance of plant and equipment

Plant or equipment	**Parameters**	**Consequence of poor control**
Patterns	Worn patterns	Dimensional inaccuracy
	Damaged or poorly finished	Cracked moulds
	Poor fixing to base plate	Finning
	Bad joints between ingates and pattern	Sand erosion, inclusions
Coreboxes	Damaged or dirty vents	Metal penetration
Moulding boxes	Worn pins and bushes	Cross joint
	Damaged boxes	Run-outs
Moulding equipment	Insufficient jolting, air or hydraulic squeeze pressure	Soft moulds - oversize castings, unsoundness, metal penetration, poor surface finish
	Inefficient stripping mechanism	Broken moulds, inclusions
Sand plant	Irregular/inefficient cleaning	Surface defects, blowholes
	Incorrect roller/plough settings	Inclusions, broken moulds
	Piping in sand hoppers	Hot sand, surface roughness
	Incorrect additions to mill/mixer	Sand erosion, inclusions, blowholes
	Ineffective disintegration of prepared sand	Poor surface finish, inclusions
	Poor screening of return sand	Blowholes, washed sand, poor surface finish
	Inefficient magnetic separation	Surface imperfections
Storage	Temperature, humidity	Blowholes

Table 8 Control of post-casting processes

Operation	**Parameters**	**Consequence of poor control**
Casting cooling and knock-out	Mould weights removed before solidification completed	Swollen castings, unsoundness
	Rapid knock-out	High residual stresses, distortion, cracking
	Delayed knock-out	Increased hardness and strength
	Ingates and feeders difficult to remove	Break-in, cracking
	Bad handling	Cracking, breakage
Cleaning	Excessive shotblasting	Distortion, cracking
	Heavy and light castings mixed in rotary barrel units	Cracking, breakage
Fettling	Heavy treatment	Cracking, breakage
	Use of unsuitable hand tools	Poor surface
	Grinding-off excess metal	High casting stresses, cracking
	Grinding jigs not used	Excess metal removed, incorrect dimensions
Casting handling	Bad handling	Cracks, breakage

5. THE STRATEGY FOR SCRAP REDUCTION AND CONTROL

High casting reject levels, both internal and customer returns, have a considerable adverse effect on productivity, delivery performance, customer satisfaction and employee morale. In addition, excessive scrap: reduces yield; wastes valuable raw materials, consumables and energy; involves management time in problem solving.

All manufacturing processes generate a certain level of scrap that is closely related to the type of casting, the processes used and the equipment available. However, in most foundries a substantial proportion of scrap results from lack of shopfloor supervision and technical control, and the use of poorly maintained and inadequate equipment.

In many cases, companies have no precise knowledge of the main causes of scrap because they fail to maintain a satisfactory scrap recording system. Many instances arise where significant quantities of castings are rejected at the knockout stage and returned directly to the melting bay, thereby bypassing the inspection team without any records being made. This is unacceptable practice; the incidence of scrap and the likely causes (and remedies) cannot be adequately monitored under these circumstances.

Scrap castings, including those returned from the customer, may represent a significant element of energy, yield and production costs. A carefully planned scrap reduction and control programme can have significant financial benefits. The value of the scrap can be quantified and the effects of action to reduce it can be easily demonstrated in cash terms. In situations where the output of a foundry is restricted by floor space or machine capacity, a reduction in scrap offers scope for an increase in potential sales revenue.

5.1 Scrap Reduction Strategy

A foundry must maintain adequate scrap records to enable quality performance to be assessed and to indicate loss of its control - when corrective action must be taken.

The essential steps that should be taken to reduce scrap and ensure high quality are:

- Segregate, accurately diagnose, and record scrap on a daily record sheet.
- Analyse scrap records to show:
  - The main causes of scrap. A weekly summary based on number, or weight of scrap castings will often provide the answers.
  - The problem castings, particularly those of high value. These should be highlighted on daily and weekly summary sheets.
- Apply corrective action to reduce scrap.
- Record the details of the action taken on a casting methods record card, and monitor the results by means of the daily scrap record, the weekly summary, and the customer returned-scrap record.

5.1.1 *Segregation and Collection of Scrap*

All defective castings, wherever they arise, should be collected and segregated into marked scrap bins or enclosures. Additional scrap returned from the customer(s) or in-house machine shop must also be segregated for inspection and subsequently incorporated in the overall scrap records. All heavy or large scrap castings should be clearly marked, e.g. with a red-paint marker, to ensure that they are not accidentally dispatched to the customer.

5.1.2 *Inspection and Diagnosis of Scrap*

At the beginning of a scrap reduction campaign, the approach to defect identification and terminology used should be standardised and agreed by the various persons involved. A standard set of photographs of defects in castings, or reference made to various publications (see below) on this subject, can be very useful for this purpose. It is also important that the team involved in the exercise should be experienced, comprising the foundry manager, inspectors, metallurgist and methods engineer. Frequently, certain defects, particularly inclusions, cannot be accurately diagnosed visually and a metallurgical examination may be necessary to provide positive identification. Unless accurate diagnosis has been made, incorrect remedial action may be taken, which could prove costly.

- *Manual of Defects in Castings (Iron Edition)*, 1994, published by The Institute of British Foundrymen.
- *International Atlas of Casting Defects*, 1974, published by The American Foundrymen's Society.

5.1.3 *Scrap Recording*

A daily record sheet suitable for use in most foundries is shown in Fig 36. This same sheet can be used as a weekly summary, the details actually recorded being varied to suit the requirements of individual foundries.

A record must be made of the number of castings inspected as well as the total produced. All castings with scrap levels above budget should be highlighted. When the high incidence of scrap is due to a particular cause, this will be clearly shown by the frequency of entries on the record sheet, giving a direct indication of where action is required.

A casting record card (Fig 37) is invaluable; it is used to assess the scrap performance of each casting. The information recorded typically includes: the foundry scrap; cause and action taken; total number, or weight, of castings produced and dispatched to customer (on an order-number basis); a summary of customer rejects, which are shown in greater detail on a separate sheet. The system should ensure that the main causes of scrap levels exceeding the budget are easily ascertained.

5.1.4 *Customer Returns*

Mutual confidence between a foundry and its customer depends upon close liaison, good communications at all levels, and the maintenance of adequate records.

It is important to diagnose and record the cause of defects for all castings rejected by customers; a suggested format is shown in Fig 38. The supplying foundry should be aware of the high cost (and inconvenience to the customer) involved when castings have to be rejected.

A casting methods card of the type shown in Fig 39, for recording the main production specification and inspection details, is a vital document. When a methods card is being maintained, there is no need to rely on the memories of supervisors and operators for important data such as details of the running system, size of moulding-box, pouring temperature, chaplet placing, etc. It is important to use the methods card for recording the dates and nature of changes in technique - or of specific materials used in manufacture.

When a casting is scheduled for return to production, everyone concerned should be reminded of the data on the casting record card relating to their specific area of supervision or responsibility. For example, what has to be controlled, and the problems encountered and rectified during the previous production runs, should be pointed out to prevent any repetition of previous shortcomings. As an alternative to keeping a separate casting record card, the reverse side of the methods card can be cross-hatched so that, in quarters of a single square, the date, production run, scrap castings and quantity outstanding for the customer can be entered (Fig 40).

Unit: **Company's name** **Date:**

Production data					Foundry scrap analysis																	Comments
					Sand and moulding						Core		Metal and casting				Handling					
Customer	Part No.	Unit	Total produced	Total inspected	Blown	Bad mould	Crush	Sand incl.	Run-out	X-joint	M.P.C.	Bad core	Slag	Cold lap	Short-run	Draw	Broken	Total scrap	Scrap % of total produced	Price per casting £	Value of scrap £	
B. J. Jones	OZP4	CT1	671	601	1		3	9	3		2	2	9				4	33	4.9	7.10	234.30	
Allens	9432	CT1	937	937	2	7	1	8	7		6	7	1	3	2	1	13	58	6.2	6.29	364.82	
Johnsons	AKR	CT1	1148	958	2	19		1		1			1		8	24	3	59	5.1	6.51	384.09	
Hopcroft	7418	CT1	2256	2150	44	28	3	14		7	16	5	2		5	143	11	278	12.3	4.09	1137.02	
CVS	5PTO	CT1	860	860	2	10	2	7	11	2	4	10	11	4	4	15	5	87	10.1	5.82	506.34	
Swift	APTI	Mech.	1480	1480	52			4						12				68	4.6	4.91	333.88	
B. Green	P4007	Mech.	428	428		4								3				7	1.6	8.33	58.31	
Ellis	PE20	BP5	191	191		4	10			4								18	9.4	6.10	109.80	
H. M. Motors	MT43	Mech.	237	216	8		5	5	3		4		7		1		4	37	15.6	5.82	215.34	
Deeley	27342	Mech.	616	420		15				5				1			11	32	5.2	9.34	298.88	
O & M	R18	Mech.	2348	2140	109	87	10	5		1	9	4		27	6	4	11	273	11.6	4.30	1173.90	
R. M. Fittings	GT28	Mech.	3183	3183		16								9			48	73	2.3	4.98	363.54	
TOTAL			14355	13564	220	190	34	53	24	20	41	28	31	59	26	187	110	1023	7.13		5180.22	
% of total produced					1.5	1.3	0.2	0.4	0.2	0.1	0.3	0.2	0.2	0.4	0.2	1.3	0.8					

Fig 36 Daily record sheet

Company's name

Scrap in excess of allowance			
Date produced	Scrap %	Main cause of scrap	Action taken to correct
13-1-81	11.6	Metal flashed over prints	Core-box modified to achieve better print fit
21-1-81	8.6	Coating over print ends	End of core print abraded
4-2-81	8.3	Vent not led through mould	Mould vent on pattern
13-2-81	1.4	No vent in core	Core print drilled
18-2-81	0.7		
25-2-81	0.5		

Production record				
Order No. and date	Quantity produced	Quanitity dispatched	Customer rejects	
			Number	Reason
2734 13-1-81	97	89	2	Blown
2734 26-1-81	67	64	1	Blown
2734 9-2-81	104	98	6	Blown
2734 24-2-81	84	79	3	Inclusions

Fig 37 Casting record card

Company's name **Date:**

Customer	Part No.	Unit	Cause of rejection														Total scrap	Price per casting £	Value of scrap £	Comments
			Pinhole	N.C.U.	Crack	Sand incl.	Distorted	Hard	Draw	Cold lap	Porous	O.O.P.	X-joint	Blown	Broken	Leak				
Hopcroft	7418	CT1				2								13			15	4.09	61.35	
C.V.S.	5PTO	CT1														3	3	5.82	17.46	
O & M	R18	Mech.				4								7			11	4.30	47.30	
R. M. Fittings	GT28	Mech.				3										2	5	4.98	24.90	

Fig 38 Customer returns record

Company's name

Customer	J. C. C. Engineering			Date	3-12-79	
Casting	End cover			Casting weight	25 kg	
Part No.	9178 AB 34			No. per box	4	
Grade of metal	17			Box size	460 x 610 x 200 x 200	
Pouring-temp. °C	1390-1420			Mould	Greensand	
Pouring-time, s	26			Moulding-machine	CT3	
				Cores	Type	Sand
Running-system	No.	Size	Area	1 per casting	Body	Shell
Downgate	1	28 dia.	629	2 per casting	Oilway	CO_2
Runner bar	1	16 x 22 x 32	606			
Ingate	4	25.4 x 4.8	484			
Pouring basin size	Standard No. 2					
Coremaking time	30 min.			Modifications*		
Mould-making time	3 min.			Date	Description	
Fettling-time/box	15 min.			9-1-80	Pouring-speed increased. Ingates modified to 32 x 5. Pouring-time 28 s	
Chills	Nil			7-3-80	Second oilway print added (chaplet eliminated)	
Chaplets	12.7 (4 dia.) x 19 (1.2 thick) for each casting			6-5-80	3 mm extra machining added to top face of cover flange	
Risers	2 off top risers, std 83 dia.			4-2-81	Feeder necks reduced to 44 dia.	

** Use thumb-nail sketches where possible*

Fig 39 Foundry methods card

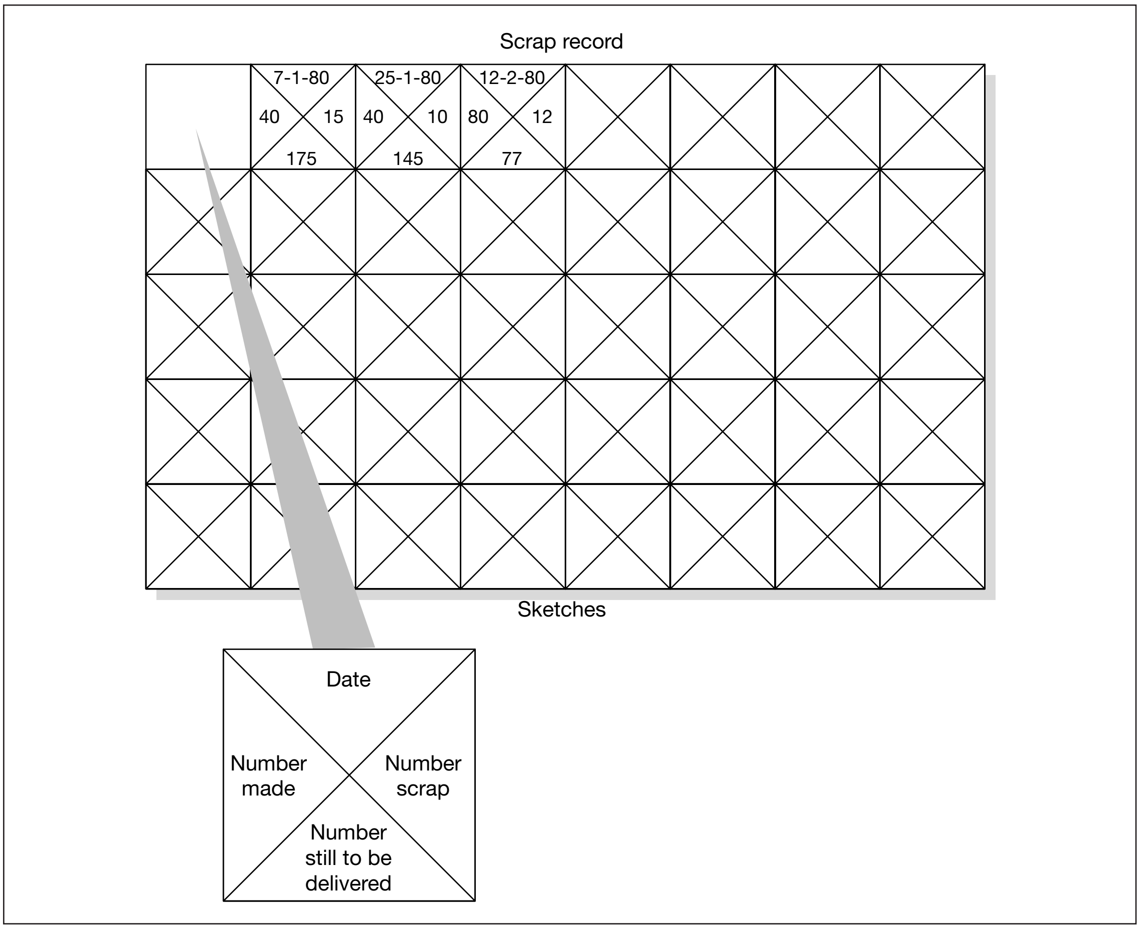


Fig 40 Foundry methods card (reverse side)

5.1.5 *Scrap Meetings*

Regular meetings devoted to the discussion of quality and scrap can help to generate and maintain 'scrap awareness' in a foundry. Adequate records, of the type described above, are essential for the efficient running of such meetings.

The frequency of scrap meetings, and the number of people required to attend, depend on the size of the foundry and the type of castings being produced. However, in general, short but frequent meetings tend to be the most effective.

The agenda for scrap meetings should include the following:

- critical examination of scrap records, including customer scrap;
- review of action taken to prevent scrap;
- discussion of problem castings;
- consideration of technical aspects of production and their effect on production rate and quality of castings.

5.2 The Importance of a Quality Management System

A scrap reduction strategy is only part of a much broader-based quality improvement and control concept. Once basic methods and process control parameters have been established for individual castings, and minimum scrap rates achieved, there are other significant factors which can change and have adverse effects on casting quality. For example: if incorrect raw materials, e.g. resin binders, ferro alloys or sand, are delivered and used, this will result in scrap castings; lack of pre-production planning can lead to the acceptance of an order that is found, later, to have inadequate production capabilities, resulting in scrap problems that are difficult to control.

There are many elements in a modern quality management system, e.g. meeting the requirement of international standard ISO 9000, which, if fully implemented, contribute to maximising quality standards and reducing scrap. The ongoing control of scrap therefore necessitates the implementation of a suitable quality management system.

KEY POINT CHECKLIST

- Develop and implement a strategy for scrap reduction.
- Segregate, inspect, and record all scrap (including customer returns) on a daily basis.
- Hold daily meetings to discuss scrap issues and decide upon preventative actions.
- Record all changes to existing practices for future reference.

6. TARGETING YIELD ATTAINMENT

When the foundry has verified that the present yield figures are reliable and accurate, a metal balance should be prepared showing where the metal that is not incorporated in saleable castings is being consumed (e.g. scrap, pigged metal, spillage, etc.). The foundry practice must then be reviewed, and achievable target yields set for the various production areas and grades of metal produced.

Unfortunately, it is not feasible to recommend a target yield figure which can be usefully adopted by any particular foundry, as much depends upon the grades of metal, type of castings produced, manufacturing facilities, and the market to be served. Furthermore, most foundries operate with a product mix encompassing castings of varying yield.

Therefore, a foundry must set individual yield targets based on an analysis of its current output.

Table 9 provides a guide to the typical yields obtained for different types of casting.

Table 9 Typical yields for different castings

Casting	**Yield (%)**
Heavy grey iron castings - simple shape	85 - 95
Medium-sized grey iron castings - jobbing or small-batch production	65 - 75
Small to medium-sized grey iron engineering and municipal castings - mechanised, volume production	65 - 70
High integrity small to medium-sized grey iron engineering castings, simple design - mechanised, volume production	60 - 65
High integrity small to medium-sized grey iron engineering castings, complicated or heavily cored design - mechanised, volume production	55 - 60
Medium-sized ductile iron castings, jobbing or small-batch production	50 - 60
Small grey iron castings - mechanised, volume production	45 - 55
Small ductile iron castings - mechanised, volume production	40 - 50

7. YIELD SURVEYS

7.1 Overview

The last major survey specifically on yield in the iron foundry industry was carried out in 1988. However, more recent information has been gathered in the preparation of Energy Consumption Guides during 1990/1 and 1994/5. The 1988 project, initiated by the Energy Efficiency Office - now the Department of the Environment, Transport and the Regions (DETR) - involved mailing a confidential questionnaire to 273 UK foundries, from which 82 replies were generated. This represented 48% of grey iron production and 70.8% of ductile iron output at that time.

The results obtained from the survey (Table 10) indicated an upward trend over a six-year period.

Table 10 Results of yield survey

	Yield (%) 1981	**Yield (%) 1986**	**Yield (%) 1987**	**Improvement in yield (%) 1981 - 1987**
Grey iron	60.5%	62.3%	63.0%	2.5%
Ductile iron	51.8%	54.6%	55.7%	3.9%

Respondents to the questionnaire suggested that improved performances had resulted principally from scrap reduction exercises, the average rate of scrap decreasing from 9.9% in 1981 to 6.1% in 1987.

A number of companies also reported that the introduction of quality management systems and more rigorous implementation of process controls had contributed to the reduction of foundry scrap.

Other factors which had stimulated improved yield were said to be:

- higher box yields;
- reduced pigging of surplus metal;
- better control of melting operations;
- improvements in metal handling and distribution;
- enhanced moulding efficiency;
- staff training.

A somewhat restricted survey of yield in iron foundries, undertaken in 1990, indicated a further improvement for grey iron production to 66.5%, but a reduction to 53.2% in the case of ductile iron. The lower performance in the ductile iron sector may have been influenced by a 56% increase in the production of such castings in the foundries which responded, and several aspects are detailed below in Section 7.2.

7.2 Aspects of Foundry Operation That Have Led to Reduced Yield for Certain Companies

Despite efforts by foundries to improve yield performance through systematic attention to all the aspects of foundry operation, it is possible that the yield position could worsen. The principal reason for this is a change in the product mix. This is particularly the case where a change in the metal grade is involved. The higher strength grades of grey iron often require heavier running

systems and ductile iron will generally require more metal in the running and feeding systems than grey iron. There has been a steady increase in the proportion of ductile iron and high duty alloy castings produced.

Lighter castings tend to have a poorer yield than heavy castings; again, there has been an increased tendency towards designing and producing thinner and lighter castings for most sectors of industry.

In recent years, there has been a significant increase in the proportion of engineering work made by the foundry industry. Poorer yields are inherently associated with these more complex, highly cored castings than with simpler castings for other markets. A change to producing higher integrity castings will often tend to depress the yield. This is because higher standards of inspection lead to a greater rejection rate and, in many cases, excessive volumes of feed metal are frequently used as a safety factor to prevent unsoundness.

7.3 Energy Consumption Guide 48, *UK iron foundry industry*

This particular Guide presents the results of a survey of the UK iron foundry industry, undertaken in 1994 on behalf of ETSU for the DETR. Again, the survey was based on a general postal questionnaire to the industry, but was supplemented by detailed questionnaires to certain target companies, and a programme of foundry visits. Including data drawn from other sources, the survey was considered to have covered 68.9% of the industry.

Although not specifically directed at yield, a number of useful indicators were obtained, as shown in Table 11 below.

Table 11 Yield figures for the foundry industry

	Good castings to metal charged (%)	**Good castings to liquid metal poured (%)**
Industry range for grey iron	48.9	55.0
Calculated average grey iron	63.7	70.7
Industry range for ductile iron	44.7	46.5 - 90.5
Calculated average ductile iron	56.0	64.5
Calculated average for all irons	61.8	68.2

Average total scrap, including internal reject castings and customer returns, was established to be 7.5% by weight of the total good castings sold.

Yield figures were quoted, where possible, for both good castings to metal charged and good castings to metal poured, as different foundries calculate their yield in various ways.

Perhaps the most important finding was that many foundries did not calculate accurate yield figures.

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